HANDBOOK OF ELECTRICAL PORCELAIN MANUFACTURE

AND OTHER CERAMIC INSULATION MATERIALS

by

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P R E F A C E

No handbook exists today dealing exclusively with the manufacture of electrical porcelain.

True enough, some text books on Ceramic Whitewares exist, but usually containing only a short description of this subject but without treating, from a practical standpoint, the numerous important methods and processes involved in the manufacture of porcelain insulators.

Some of the methods employed today stem from ancient times, most of the others of more recent date. But they all combine that practical "know-how" which is still the most important ingredient in this industry.

The flow of production here, from the receipt of the raw materials to the shipment, is a progressive one, involving the use of modern machinery, experienced operators and engineers and years of accumulated knowledge and experience in this field.

Throughout this handbook an effort has been made to supplement descriptions of the various manufacturing methods by carefully selected photographs and illustrations which has the advantage of compressing a great deal of information into a small space.

C O N T E N T S

HANDBOOK OF MANUFACTURE OF ELECTRICAL PORCELAIN AND OTHER CERAMIC INSULATION MATERIALS

Chapter I. Introduction - History

Electrical porcelain is a highly vitrified, non-porous product used for electrical insulation at very low or extremely high voltages. It has high resistance to heat, chemicals, moisture, aging and high dielectric and mechanical strength.

In fact, its vital role in insulation makes electrical porcelain the material absolutely essential to the production and distribution of present day electric power.

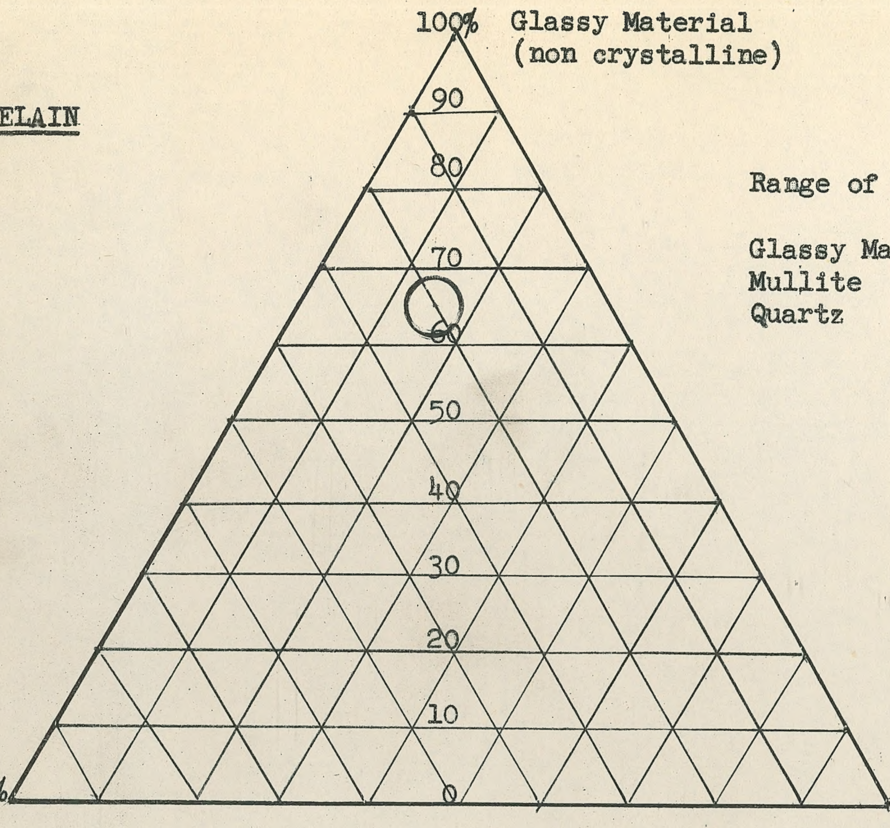
Electrical porcelain of the conventional type, chemically considered, is a double silicate of sodium or potassium and aluminum. It is composed of kaolin or china clay, ball clay, feldspar and flint. The triaxial diagrams, Figure 1 and Figure 2, show both average chemical and mineralogical compositions of high voltage porcelain as manufactured today.

The electrical porcelain industry requires the knowledge of ceramic and electrical engineers as well as a great amount of know-how because of the great complexity of its processing.

The history of electrical porcelain manufacture at General Electric will be discussed here only briefly. Of interest to G.E. engineers may be the fact that Fred M. Locke at Victor, New York in 1893 produced the first wet-process insulator. Locke's first insulators actually consisted of vitrified stoneware clay which was available around Victor; no feldspar or flint was used. The glaze was made from a red-firing low fusible clay known as Michigan slip to which feldspar was added. For many years later and in fact up to recently some electrical porcelain manufacturers (Ohio Brass Company) still used Michigan and Albany slip clay, both of similar composition, in their brown glazes.

At Schenectady, New York, the General Electric Company operated an electrical porcelain plant from 1902 to the end of 1956. Another General Electric porcelain plant for dry-pressed and small cast ware was in operation at Pittsfield, Mass., from 1922 to 1931. The Locke plant at Victor was closed in the early 1930's. Today the only remaining, greatly modernized General Electric electrical porcelain plant is now at Baltimore, Maryland, having begun its operation here in 1922.

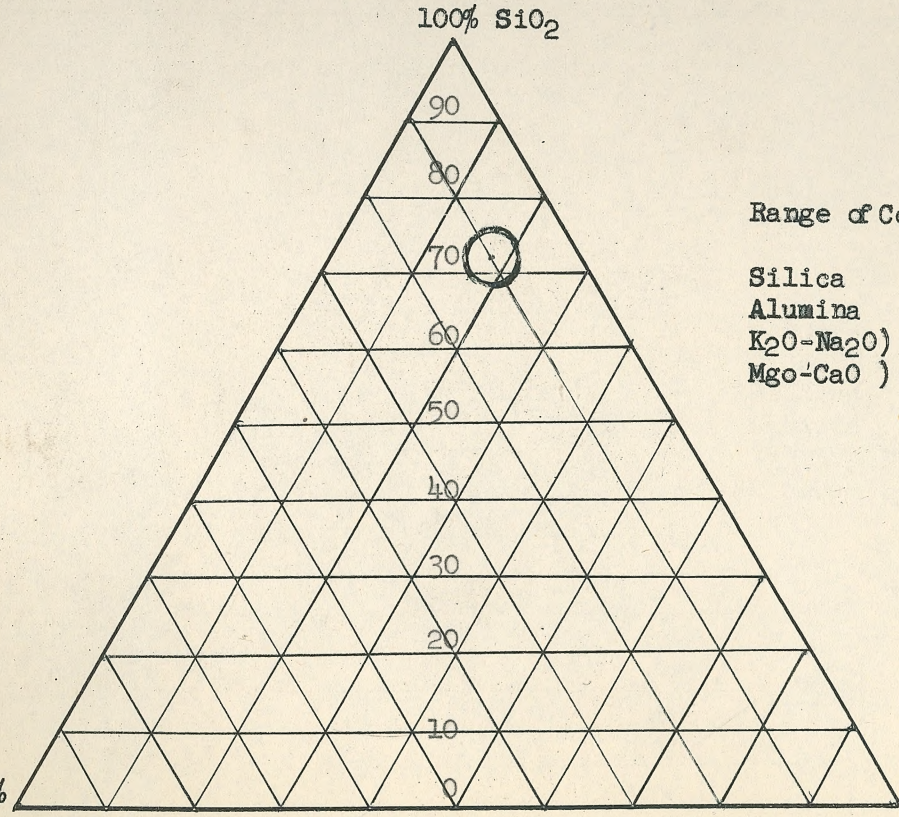
ELECTRICAL PORCELAIN



Range of Commercial Bodies

Glassy Mat.	60-65%
Mullite	19-24%
Quartz	13-16%

Mineral Composition



Range of Commercial Bodies

Silica	70-72%
Alumina	21-23%
K_2O-Na_2O)	
MgO-CaO)	4.5-6.0%

Chemical Composition

FIGURE I

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It may be of interest to mention here that at Victor and Schenectady a great many "first's" were introduced into the insulator industry. Examples of these were the first continuous humidity controlled drier (1917) tunnel kiln (1913), continuous filtration, casting process for large transformer bushings (1914), dry pressing under vacuum and many others during the more recently completed extended modernization and expansion program at our Baltimore plant.

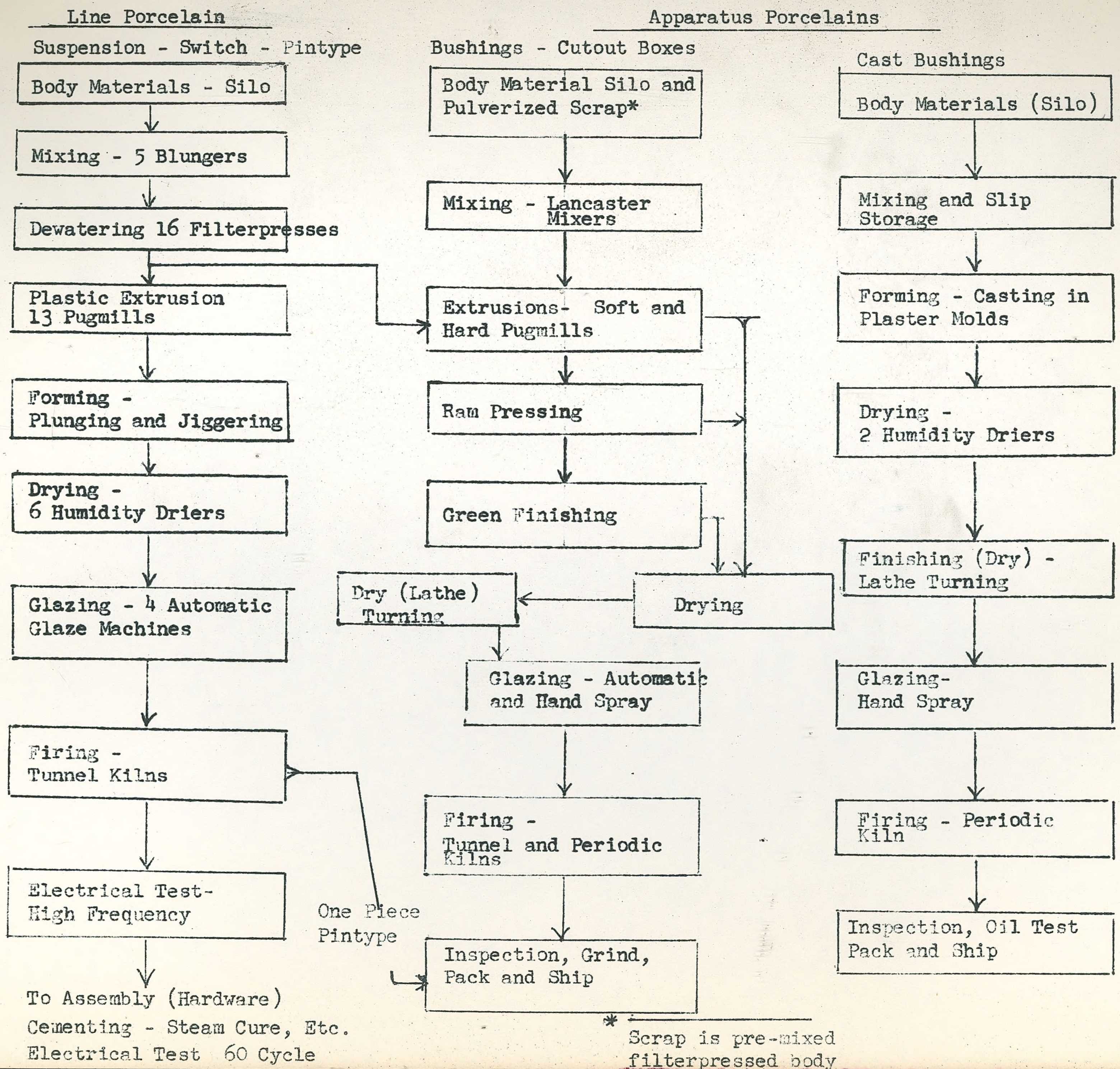
Insulator Manufacture Methods and Processes

The methods employed in the manufacture of porcelain insulators can best be illustrated in the form of Flow Charts.

Two of such charts are herewith presented, one for our Insulator Department of General Electric and the other for manufacturing methods employed by the Illinois Electric Porcelain Company at Macomb, Illinois. There are actually very little differences in the methods of manufacturing at the Baltimore and Macomb plants, but whatever they are will be discussed in a later chapter on "Body Preparation and Processing".

SCHEMATIC FLOW CHART

INSULATOR DEPARTMENT, GENERAL ELECTRIC COMPANY, BALTIMORE, MARYLAND



Chapter II. Raw Material Requirements

RAW MATERIALS

Sources

Compositions

Control

Once the requirements of an electrical porcelain have been established, the problem becomes one of how to select and combine the raw materials (clays-feldspar-flint) in the right proportion to obtain a body that will meet a host of complex processing requrements. Such are filterpressing without delay and segregation, pugging without structural defects, hot-pressing or plunging without distortion, fast-rate drying without cracking, and firing without porosity or bloating and many other requirements.

In view of this it is quite obvious that the raw materials must be selected with the utmost care.

Likewise, complete technical information of the raw materials is most important especially when it becomes necessary to substitute materials of which a supply has depleted.

Since the early porcelain workers in America came from foreign countries, especially from England, they preferred raw materials with which they had long been familiar. For many years then the thought prevailed that certain clays had to be imported in order to produce a satisfactory porcelain. Therefore, up to about 20 years ago, American made high voltage porcelain compositions contained ball clays from the Devon and Dorset districts, and china clay from the Cornwall mines. Some American electrical porcelain manufacturers still use such foreign clays, but in considerable smaller amounts, i.e. with additions of some domestic ball clays. Of interest is that some of the older American high voltage porcelain compositions closely resemble those of Bullers, Taylor, Tunnicliff & Company, etc. Likewise, the firing temperature and oxidizing atmosphere in British plants are very close to those maintained in our American kilns.

During World War I the Locke (Victor) plant, plaqued by shipping delays and curtailments caused by wartime conditions, turned to domestic ball clays and pioneered in developing an "American Body" for porcelain bushings. Both the "English Body" and "American Body" were used for many years thereafter at the Victor and the newly built Baltimore plant.

Ball Clay for Wet-Process Bodies

It is generally recognized that one of the most important, and least controllable, ingredients in electrical porcelain bodies is ball clay. Used from the earliest days of body developments and still used today, ball clay has proved indispensable. At the same time, partly due to lack of technical information or improper amounts used in body compositions and partly due to poor control at the mining operations, no other raw material has been so much the cause of failures and manufacturing losses than ball clay.

In American wet process body compositions, the amount of ball clay varies between 25 and 30 percent.

Within the last 20 years, ceramic research conducted at General Electric porcelain plants have resulted in wet-process formulae containing domestic ball clays, china clays, flint and feldspar entirely from the North American continent. These domestic porcelain bodies are mechanically and electrically equal to those containing foreign clays.

The present G. E. No. 740-1 standard wet-process body contains two domestic ball clays which are described as follows:

Mississippi (M&D) Ball Clay

Ball Clays in General Electric Wet-Process Bodies

Used in the Schenectady wet process body since 1939 as a substitute for English ball clay, this Mississippi clay has shown good uniformity over the years. The Baltimore plant began using M&D clay in 1948 (Experimental Body No. 920-F740), replacing with it the Hanover (Maryland) ball clay, which due to great variations in quality, became a source of considerable manufacturing losses.

In Figure 1 complete data of the chemical and physical property of the Mississippi ball clay is presented. The high plasticity of this ball clay is due to the extremely fine particle size and also the presence of about 20% montmorillonite. Ball Clays, containing this clay mineral montmorillonite, are more sensitive to firing. Therefore, the present 16% in the 740-1 wet-process body, should be considered as the maximum amount that can safely be used. The M&D ball clay is used in the Ohio Brass and Knox wet-process bodies.

No. 10A Tennessee Royal Ball Clay

No. 10A Royal ball clay is supplied from a district from which for many years ball clay for us and our competitors have been supplied. The present 10A is a blend of lighter and darker ball clays, closely controlled and blended from pre-tested storage sheds. In Table No. 2 chemical and physical data based on extensive laboratory tests are shown.

Ball Clays Used by Other Manufacturers

The following domestic ball clays are also of considerable interest as they are used by other insulator manufacturers in their wet-process bodies:

Bell Universal Ball Clay (Bell Clay Co., Gleason, Tenn.)

This ball clay is a blend of two Tennessee clays (50% Dresden and 50% Dark) which has been used by the Lapp Company for more than 20 years. Complete data is presented in Table 3. Only 15% of this high plastic ball clay can be used in the body, as the appreciable amount of carbonaceous matter in the clay would, at present fast firing rates, cause incomplete oxidation and the formation of "blue core" in the porcelain. Since 1955, Lapp has been interested in a cleaner, equally high plastic ball clay (Regal) mined by the United Clay Company in nearby Tennessee deposits.

No. 5 Dark Tennessee Ball Clay (Kentucky-Tennessee Clay Co., Paris, Tenn.)

This is a very dark colored ball clay which has been supplied to the Ohio Brass Company for many years. It is one of the strongest domestic ball clays, dry modulus of rupture being 1080 lb/psi. Most other ball clays from these mines average 600-800 lbs/psi. The Ohio Brass Company uses only 14% in their plastic body, as a higher amount would introduce too much carbonaceous matter in the body and cause trouble in firing. A sample of this ball clay of which the supply is limited and restricted to Ohio Brass shipments, was tested in our Ceramic Laboratory, but it appears that the only reason Ohio Brass is using such a ball clay is the high dry, i.e. bonding strength in the body. Such property can also, and with better advantage, be obtained from some cleaner domestic ball clay.

Victoria Tennessee Ball Clay (United Clay Mines Corp., Trenton, N.J.)

This is one of the Tennessee ball clays which is used, together with two others, namely Old Mine No. 4 and Kentucky Special, in the Victor Insulator Company's wet-process body. The Victoria clay is a moderately dark, fine grained clay (63% is finer than 1

micron). The dry modulus is not high, 575 lbs/psi. The clay contains a high amount of ligneous material (3.68%),the coarser which must be removed by careful screening, but an appreciable amount still passes through the factory 100 mesh screens into the body. The Victor plastic body is considered a "soft", i.e. a low strength body in the dry state, not favorable to the manufacture of large size insulators.

Old Mine No. 4 and Kentucky Special Ball Clay (Kentucky-Tennessee Clay Company, Paris, Tenn.)

Perhaps no other clay has been better known and used so widely in electrical porcelain bodies as the Old Mine No. 4 ball clay. This clay, together with the Kentucky Special was used in the "American" body at Victor and Baltimore and at Schenectady for many years. In 1955 the supply of these ball clays became exhausted, but substitutes from nearby mines were offered as New Old Mine #4 and New Kentucky Special ball clays. A 50/50 mixture os these clays is now used in the Baltimore No. 300-2 casting body under the designation No. 817 ball clay. These ball clays are used in wet-process and casting bodies by Westinghouse at Derry, Porcelain Products and Victor Insulator Company.

Tables No. 4 and 5 contain complete chemical and physical data on these ball clays.

Imported (English) Ball Clays

English Ball Clays

Past and Present Use

Since the earliest days of insulator manufacture at Victor and Schenectady, and up to about 1940, English ball clays were used entirely in wet process porcelain bodies. The Canadian G.E. porcelain plant at Peterborough used up to its closing in 1955, English ball clay in the wet process body.

At the Victor and Baltimore plants a very plastic, but highly ligneous ball clay, known as "M & M" was used in the "English", i.e. lineware body. This ball clay also contained fine sand and was subject to considerable variations. Therefore, a special ball clay blunger was installed where this ball clay was thoroughly mixed with water and made into a thin slip of density 1.15. The slip was lawned in a vibration screen to remove large particles of impurities. In the meantime the other body ingredients, i.e. china clay, feldspar and flint, were weighed into a ball mill and the ball clay slip in the proper quantity was added. Then the complete body slip, having a density of approximately 1.40 was filterpressed and worked in the usual manner. However, much of the very fine lignite particles were dispersed into the body. In these earlier days, with the then only

available round, bottle-shaped, coat fired kiln, much trouble with bloated, discolored and "blue-core" ware was encountered. Some years ago it was standard practice to ball mill complete porcelain bodies for several hours to control the grain size of the non-plastic ingredients. When finer ground flint and feldspar became available, this costly and slow ball milling practice of the porcelain was abandoned. Today, only special ceramic (high alumina, zirconia or titania) bodies are ball milled before filterpressing.

At the Schenectady plant no such special ball clay blunging equipment was available and, therefore, cleaner English ball clays were purchased. For many years high plastic English ball clays with excellent firing range such as Bedminster (Dorset) and No. 11 (Dorset) clays were used in the wet process bodies. "Blue core" and bloated insulators were, therefore, partically unknown at the Schenectady plant.

No. 149 English Ball Clay - Moore & Munger, New York

As will be shown later in the chapter on "Body Compositions", English ball clay is still used by some American electrical porcelain manufacturers. The most widely used is No. 149 ball clay, imported from the North Devon clay mining district, a blend of dark and lighter colored clays. It has a high plasticity and its bonding strength (dry modulus) is in line with the better grade Tennessee ball clays. Table No. 6 contains the complete chemical and physical properties of this No. 149 ball clay.

Ball clays are employed because of (a) their plasticity, (b) dry strength, and (c) as a secondary aid to vitrification. Experienced ceramists know that each ball clay must be considered as an individual and that the above properties and the performance in a body are determined to a large degree by the clay-mineral components present.

There are appreciable differences in the composition and properties of English and domestic ball clays, which will be discussed in the following:

English and American Clays - Chemical and Mineralogical Differences Compared

1. In years past, porcelain manufacturers preferred English clays, because domestic clays were found to be not uniform with succeeding shipments. Today, American clays are produced in quality and uniformity equal, if not superior, to imported clay. Today, most American clay producers are employing ceramic engineers in laboratories equipped for modern silicate research and quality control work.

Tennessee Ball Clay Mining
United Clay Mines, Gleason (Tenn.) II

Regal

Stratton

Regal Ball Clay (bottom of pit)

This is a light gray colored clay, very fat. Stratton ball clay at fron is less plastic - white colored clay. Regal ball clay is used by Pinco and Lapp Co.

Victoris Ball Clay Pit

The ball clay (part of G.E. Roy 10A blend) is found at the bottom of this deposit.

Photos by
L.E.Thiess-1956

2. English Dorset and Devon ball clays differ from American clays in the amount of fluxes. The total amount of fluxes K_2O, Na_2O, CaO and MgO) in the No. 149 English Clay is 3.40% against that of only 1.95% in the Royal A-10 (Tenn.) ball clay. English ball clay vitrified completely between pyrometric cone 4-6. The Tennessee and Kentucky clays do not vitrify below cones 10^- and 12. Less feldspar or other fluxes are required in bodies containing all English ball clays.

3. The mineral composition of English ball clays differ also from domestic clays in that they contain up to 20% illite, whereas American ball clays may contain up to 20% montmorillonite, the remainder in both types being, of course, kaolinite. Illite containing clays are less plastic and have much lower bonding strength (dry modulus of No. 149 English clay is approximately 800 lb./psi, that of M&D Mississippi clay is approximately 1400 lb./psi). Montmorillonite containing clays have a much finer grain size, i.e. higher amount of colloidal fraction, higher plasticity and higher base exchange capacity. In general, these clays are sensitive to drying and firing, therefore, the amount used in a wet process body should not exceed the absolutely necessary for satisfactory hot plunging work (12-16%).

4. The grains in illite clays are more of a coarser platey nature, the plasticity of such clays, therefore, being relatively less than that of montmorillonite clays.

Electrical Porcelain Manufacturers Use Two or Three Ball Clays in Wet-Process Bodies

As will be shown later in the chapter on "Body Compositions", most electrical porcelain manufacturers today do not use, as in years past, one single ball clay, but use at least two, some even three different kinds of ball clay in their wet-process body compositions.

5. Electrical porcelains made from wet-process bodies containing English ball clays show no superior electrical and mechanical properties over those containing domestic clays. However, some of the users of these clays, as for instance, ceramic engineers of the O.B. Co. maintain that the manufacturing losses, especially on switch shells and line posts are lower with their English ball clay body than with an all domestic ball clay body which they have run for a few months at a time to see whether English clays could be eliminated. This subject will also be discussed in detail in chapter "Body Compositions"

Mining and Refining of Tennessee Ball Clay at United Clay Mines, Gleason, Tenn. I

The G.E. Supply of Royal No. 10 ball clay comes from these mines.

Ball clay mining consists first of testing the size of the deposit and the quality of the clay by drilling holes every 50 feet. Then the overburden, often as high as 60 feet, consisting of soil, sand and lignite, is stripped to expose the ball clay veins. The clay is cut and moved to trucks by a dragline.

As shown in these photographs, there are usually two, often three, different kinds of ball clay. They are usually of different color - brown, gray, lighter and darker. Some ball clays look almost black. Experience tells the clay mining superintendent how to keep these clays separate.

In this photograph the good ball clay (Royal) is shown at the bottom of the pit; the Rex ball clay vein is just above the Royal clay. The Victoria ball clay, shown on photo No. 3 is mined at another, nearby pit.

The mined ball clays are brought by trucks to the processing plant where they are run through a disintegrator directly in a storage bin provided for each clay.

The Royal 10A ball clay consists of a blend of the above three clays. Blending is done by taking the clays from the storage bin by a payloader; then these clays are mixed again when blown into the railroad car by a belt flipper.

So far only ball clays have been described for use in wet-process bodies. Ball clays for casting bodies have to meet different requirements. Therefore, this will be discussed in the chapter on "Casting Bodies".

China Clay - Kaolin

The earliest porcelain insulators, especially those made in Europe, were made from bodies containing only china clays or kaolin. With ever increasing voltages and consequent larger size insulators, ball clays had to be added to increase the plasticity of the body and the dry strength of the unfired ware. On the other hand, there are a number of valid reasons why an all ball clay body cannot be made into a good piece of ware. Therefore, a proper ratio of ball clay and china clay, based on experience and operating results, is necessary in a wet-process body.

English china clay from Cornwall mines has been used in the Baltimore wet-process bodies up to about 1940, when a changeover to domestic china clay was made. At the Schenectady plant, English china clay was discontinued and replaced with domestic Georgia and North Carolina kaolins in 1932.

However, English china clay is still used in the Baltimore casting body, No. 300-2. The Schenectady casting body contained only domestic china clays.

The term "China Clay" is used more for English and that of "kaolin" (from the Chinese Kao-ling) used more for domestic clays. With both materials we deal with a more or less white colored, feebly plastic or chalky material, consisting of amost 100% of the mineral kaolinite.

Domestic Kaolins in G.E. Wet-process Body

Two domestic kaolins are now used in G.E. 740-1 standard wet-process body. In the following a description of these kaolins will be given.

Kamec (N.C.) Kaolin - Harris Clay Co., Spruce Pine N.C.

This North Carolina kaolin is only the primary kaolin known in the United States. It corresponds most closely to English china clays in physical and chemical properties. But this Kamec kaolin is finer grained, more plastic, and stronger than English china clays.

The Kamec kaolin, consisting of about 90% of the mineral kaolinite, has varied at times in small amounts of gibbsite ($Al(OH)_3$)., i.e. hydrated alumina and fine grained white muscovite mica.

Another clay mineral present in amounts of approximately 30% is halloysite ($Al_2SiO_5OH_4$). As with ball clays, so also with china clays or kaolins, it is important to know the type of clay-minerals present, because the shape and grain sizes of these differ and affect the physcial properties of a clay. Table 7 shows the chemical, mineralogical and physical properties of Kamec Kaolin.

No. 27 Georgia Kaolin - Southern Clay Co., New York

This kaolin, as all others from Georgia mines, is a secondary clay and its physical properties are somewhat different from the primary kaolins. The Georgia kaolins are usually lower in fluxes. For instance, the total K_2O, CaO and Na_2O content of the No. 27 kaolin is 0.77%, that of Kamec kaolin is only 1.64%. Therefore, the Georgia Kaolin is more refractory than the North Carolina Kaolin. The chemical and physical properties are shown in Table 8. The Georgia kaolin, before processing, contains a certain amount of ultra-fine particles which are removed by a fractionation process, so that the kaolin shipped to ceramic plants, is of the required controlled grain size.

Domestic Kaolins

Domestic Kaolins Used by Other Insulator Manufacturers

Some electrical porcelain manufacturers, as for instance Westinghouse at the Derry plant and Porcelain Products at Parkersburg use a Georgia kaolin known as Pioneer Clay.

Pioneer Kaolin - Georgia Kaolin Co., Dry Branch, Georgia

This is a water-washed, fine grained kaolin, 40% finer than 1 micron, with this fineness controlled by a centrifuging process. The dry strength is high (350 lb/psi) against 20-30 lbs./psi for the fractionated, coarser grained Georgia Kaolins. (Used in Westinghouse and Porcelain Product wet-process bodies).

Two other, but unrefined (crude) Georgia china clays are used by other electrical porcelain manufacturers. These clays are supplied by the United Clay Mines Corporation as follows:

North Carolina (Kamec) Kaolin

This primary kaolin is mined near Spruce Pine, N. C.

The raw kaolin as taken from this mine contains a large amount of very fine mica flakes and small quartz grains which must be removed by washing. The present method of refining this product yields about half of the kaolin, the other half being lost in the washing process.

Kamec Deposit - Top overburden in red soil and sand.

In this plant, containing the most modern equipment for processing raw kaolin into a refined, grain size controlled product, the Kamec clay used in G.E. wet-process body is produced. Mica is recovered by a froth floatation process.

Kaolin Processing Plant.

Kingsley China Clay and Layton China Clay

The Kingley clay is very fine grained (84% finer than 1 micron). Dry strength 106 lb/psi. 20% is used in the Victor body.

The Layton clay is somewhat coarser, but still 78% finer than 1 micron. The clay has a very high shrinkage and the dry strength is also high (948 lb./psi) which is due to the presence of montmorillonite, i.e., bentonitic material in this clay. 9% Kingsley and 8% Leighton clay are used in the Pinco wet-process body. Experience by users has shown that such crude, unrefined china clays vary often considerably in quality and uniformity from shipment to shipment, and they are, therefore, not recommended for use in high-grade electrical porcelain.

English china clays are still used in large quantities in the American porcelain industry, in spite of considerable higher costs. The best English china clays come from Cornwall mines, including the following, which is used in Lapp's and Ohio Brass' wet-process bodies and also in G.E. No. 300-2 casting body.

MWM China Clay - Moore & Munger, New York

ENGLISH CHINA CLAYS

This china clay is washed, conditioned for controlled grain size and filterpressed. This process insures good uniformity from shipment to shipment. The chemical and physical data for this clay is shown in Table 9.

Fine Grained Vs. Coarse Grained China Clay

As has been shown by the foregoing chapter on China clays and Kaolins, these differ one from another in many properties, depending on origin and processing. Important for the use in plastic bodies are the rheological properties, particle size distribution and green (unfired) strength.

As for the proper selection and use of fine grained vs. coarser grained (fractionated) china clays in wet-process and casting bodies our own long years experience in this field agrees well with that of other outstanding and successful manufacturers of electrical porcelain, namely that:

(a) A good wet-process body, meeting all processing requirements, should contain a high plastic, fine grained, clean and strong ball clay, or a blend of these, and

(b) Coarser grained china clay or kaolins instead of the finer grained variety. The best results have been obtained by the use of the water washed and grain size controlled North Carolina, Georgia and Cornwall (English) china clays. Some more on this subject will be said in Chapter III - "Wet-Process Bodies".

Feldspar in Electrical Porcelain Bodies

Feldspar

Feldspar is the universal flux in electrical porcelain. Its proper selection and control is important and becoming more so with the present trend in the industry to increase the speed of kiln firing.

Commercial feldspar, as supplied today from domestic mines in Virginia, North Carolina or South Dakota is actually a mixture of several feldspar minerals, occurring in the same mine. These minerals are orthoclase (or microline) $K_2O \cdot Al_2O_3 \cdot 6SiO_2$, called "potash spar", albite - $Na_2O \cdot Al_2O_3 \cdot 6SiO_2$, called "soda spar", and anorthite - $CaO \cdot Al_2O_3 \cdot 2SiO_2$, called "lime spar". None of these feldspars is ever used alone in electrical porcelain bodies. The amount of lime spar in ground commercial feldspar is present only in very small quantities and usually occurs in solid solution with the potash feldspar mineral.

In any case, such high lime containing feldspars are undesirable in electrical porcelain compositions. Even smaller quantities bring about a sharp increase in fusibility in the feldspar glass and cause blistering or bloating in the fired body.

In the following, five commercial feldspars, approved and used by General Electric and other leading electrical porcelain manufacturers are given:

Approved Sources

Chemical and Mineral Composition

Representative Chemical Analysis	#1 Virginia (Moneta) Feldspar	#2 N.C. (Celo) Spar	#3 S.D. (Keystone) Spar	#4 New Hampshire Spar	#5 Ga. G200 (Monticello) Flotation Spar
SiO_2	68.40%	68.70%	68.40%	67.98%	65.56%
Al_2O_3	17.40	17.44	17.50	17.10	19.48
Fe_2O_3	0.09	0.09	0.08	0.09	0.06
CaO	0.20	0.22	0.20	0.11	0.98
MgO	trace	nil	trace	0.09	trace
K_2O	10.80	11.00	10.40	10.82	10.36
Na_2O	2.70	2.35	3.30	3.34	3.20
Ign. Loss	0.35	0.38	0.20	0.44	0.20
	99.94%	100.18%	100.08%	100.97%	99.84%

Users of Feldspars

Feldspars No.1 and No. 2 are now used at G.E. Baltimore plant. No. 4 was used at Schenectady.

Lapp Insulator Corporation presently purchases feldspars No. 1, 2 and 5. The latter is also supplied to Victor Insulator Corporation.

Ohio Brass and Illinois Porcelain Company use feldspar No. 3 in their wet-process bodies. Westinghouse (Derry) plant uses No. 1 feldspar in wet-process and casting bodies.

The chemical analysis alone is a decided help in selecting a feldspar, but the calculated mineral composition provides a check upon the analysis, permits of adjustment to take care of free quartz content, and above all, gives the actual feldspar minerals present, each of whose action has a distinct bearing upon the quality of the fired porcelain.

To determine the amount of these feldspars and free quartz present in the above listed feldspars, the following factors may be used. Factor 5.93 for K_2O, 8.44 for Na_2O, and 4.98 for CaO, multiplying these by the percent alkali in the analysis gives the percent of each feldspar mineral in the ground commercial product.

Calculated Mineral	Feldspar #1	Feldspar #2	Feldspar #3	Feldspar #4	Feldspar #5
Microline (potash spar)	64.0%	65.23%	61.67%	64.16%	61.43%
Albite (soda spar)	20.79	19.83	27.85	28.18	27.00
Anorthite (lime spar)	1.00	1.10	1.00	0.55	4.88
Total Feldspar	85.79%	86.16%	90.52%	92.89%	93.31%
Excess Quarts (major) and Kaolin (minor)	14.21	13.84	9.48	7.11	6.69

Feldspars No.3 and No. 4 are more fusible than those marked No. 1 and No. 2. The No. 5 (Monticello) feldspar is low in silica but too high in lime spar and would not meet G.E. requirements. In substituting one feldspar for another, any free quartz should be counted as flint in the body formula and replacements made on the basis of actual feldspar content.

Feldspar is the source of the fluxing element needed for the formation of glass by reaction in the body. Its strong solvent action will be understood,considering the fact that while only 30% feldspar is contained in the unfired body composition, the quantity of glass developed in the fired body, as shown in triaxial diagram Figure 1, normally 2 to 2½ times that of the feldspar used. Of all the fluxes, that may be used in a porcelain body, potash feldspar is the safest. This is due to its peculiar, two-phase fusion behavior. First, at 1150°C ± °C it melts to form the (glassy) crystals leucite and a viscous siliceous glass. Leucite and the glass may coexist up to about 1500°C, at which time the leucite crystals disappear. The fused feldspar glass and lucite crystals, both being isotropic, cannot be seen in the polarized microscope, only the undissolved quartz grains may be seen (and the amount actually counted) by viewing under crossed nicols.

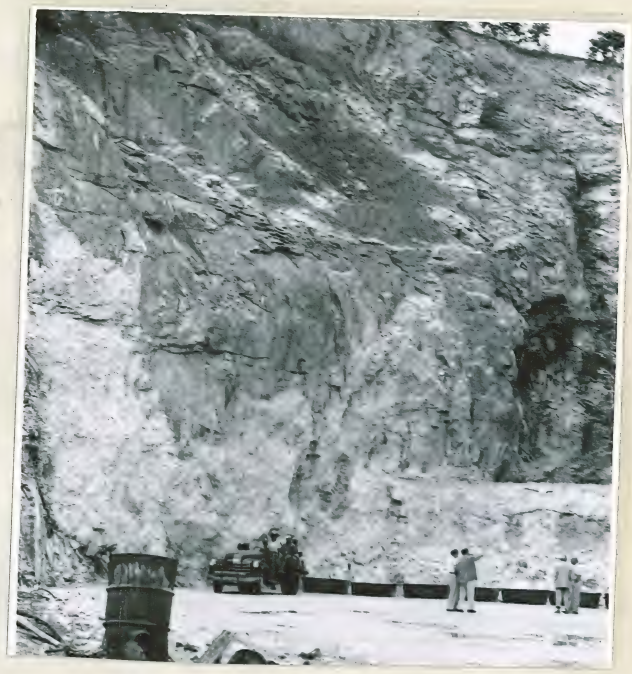
Solubility in Water

Electrical porcelain manufacturers have always insisted on potash feldspars low in soda (Na_2O) content. The reason for this is that high soda spars fuse at lower temperature and more suddenly and cause slumping and warpage during firing of large, heavy porcelain pieces. Finely ground commercial feldspars develop solubility in water, especially in the hot water now used in blunging porcelain slip. This leaching out of certain amounts of the alkalies brings about a rise in the pH and a deflocculation (thinning out of the slip). Therefore, a chemical treatment of the slip

Feldspar Mining at Spruce Pine, North Carolina and Bedford, Virginia

G.E. Supply of Moneta and

Celo Feldspar



Depth of mine bottom with good feldspar dike (marked) 60 ft. from top.

After drilling and blasting, assorted rock feldspar is hoisted to surface and loaded into trucks to be transported to grinding mill.

Here, good feldspar is hand cobbed, quartz, garnet, mica, iron stained spar, tourmaline, etc., discarded as scrap.

Photos by L. E. Thiess
1952/57

by acids, acid or neutral salts (flocculants) is necessary to prevent segregation in the filtered plastic body. This important subject will be discussed in a later chapter on "Body Preparation".

Most insulator manufacturers, including G.E. are using two feldspars of close composition in their porcelain bodies. High grade potash-low soda feldspars have in recent years become rather scarce in supply and the dealing with two reliable suppliers has become both an advantage and necessity.

The photos taken by the writer in 1955 show the deposit and mining operations at the Clinchfield Sand and Feldspar Corporation at Bedford, Virginia.

A diagram showing grain size distribution and results of screen tests is attached.

Flint in Electrical Porcelain

Pottery Flint

Commercial ground flint is almost 100% quartz, i.e. crystalline silica (SiO_2). Pottery flint is the purest, least variable and best controlled of the ceramic raw materials used in porcelain bodies.

For more than 50 years flint from Pennsylvania has been used by electrical porcelain manufacturers. Today flint of same high quality is also supplied from Virginia deposits. The G.E. No. 740-1 wet-process body and No. 300-2 casting body contain flint from both quartz mines.

Chemical Composition

The chemical composition of these flints are as follows:

Chemical Analysis	Shenandoah (Va.) Flint	Pennsylvania (Mapleton) Flint
Silicon Dioxide (SiO_2)	99.66%	99.68%
Iron Oxide (Fe_2O_3)	0.04	0.04
Aluminum Oxide (Al_2O_3)	0.06	0.09
Calcium Oxide (CaO)	0.07	0.02
Titanium Oxide (TiO_2)	0.02	0.03
Magnesium Oxide (MgO)	trace	0.01
Ignition Loss	0.18	0.15
	100.03%	100.02%

Function in Bodies

The role of pottery flint in ceramic bodies is to reduce the drying and firing shrinkage and the promotion of toughness and strength in the fired body. In years past flint was ground much coarser than today, with a poorly controlled 10-12% residue on the No. 325 mesh (44 micron) sieve. This resulted quite often in porosity and inferior dielectric strength in porcelain insulators. Today, most of the commercial flints are ground to such a degree of fineness that 95% will pass a No. 325 sieve. Actually, it is the material in the subsieve ranges that is most important in the vitrification behavior and strength of the fired porcelain.

Importance of Grain Size

Increase vitrification in porcelain bodies may be secured by using a more finely ground feldspar, but this is relatively less important than a finer particle size of flint, especially at the present trend of faster kiln firing.

Subsieve particle size and screening data of the approved two pottery flints is shown in attached diagram.

Firing Behavior

The amount of pottery flint in American H.V. electrical wet-process porcelain bodies varies between 18 and 24%, with G.E. porcelains containing 20%. Unlike feldspar, which fuses completely in the firing range of commercial kilns, flint, especially the larger grains, remains practically unchanged in the fired body. Petrographic studies of the microstructure of fired electrical porcelain show a certain degree of solution or glassy reaction rims around the boundaries of the quartz grains. Occasionally also fractures or cracks in the

G.E. Supply of Pottery Flint

Pure crystalline silica is produced from quartzite, a sparkling white granular rock, composed of more than 99% SiO_2.

The hard quartzite rock is drilled with heavy-duty pneumatic machines, blasted and the rock pieces run through jaw crushers, washing machines to remove yellow clay materials. After the granular - white sand is dried, it is ball milled to 325 mesh fineness in contineous operation. The final train size is controlled by air separation.

Quartzite Mine - Shenandoah Silica Co.
Gore, Virginia

Quartzite Mine
at Berkeley Springs,
West Virginia

Photos by L.E. Thiess
1956

large grains are shown, caused by strains in cooling due to lower thermal expansion of the glassy phase and a higher expansion of the quartz grains. One more reason why flints of a very small particle size should be used.

X-ray diffraction analysis of fired electrical porcelains show that only a relatively small amount of flint is dissolved in the glassy phase. In a fired body, containing 20% of flint in the raw (unfired) composition, 13-16% remained as undissolved quartz. As quartz is subject to a crystalline inversion, accompanied by sudden volume changes, fired bodies are very sensitive to sudden temperatures, especially around 575°C, i.e. the conversion from α to β quartz, therefore, fired porcelain must be cooled carefully to avoid cooling cracks.

The photos which accompany this chapter on flint have been taken at the quartzite quarry of the Pennsylvania Glass Sand Corporation, at Berkeley Springs, West Virginia.

Table 10 - Locke (Victor) and Baltimore Wet-Process Bodies

Raw Materials	English Bodies		Domestic Bodies								
	110	128	117	124	135	740	740A	740G	740-P	789	740-1
M&M English Ball Clay	26.0	26.0									
Kentucky Ball Clay			26.6	30							
Mississippi Ball Clay						15	15	15	18		16
Tenn. Royal Ball Clay						15	15	15	18		14
Tenn. Victoria Ball Clay										30.0	
Md. Hanover Ball Clay					30						
M&M English China Clay	20.6	20.0	19.9								
S.C. (Huber) China Clay				16	14						
N.C. Kamec Kaolin						10	5				12
Ga. Pioneer Kaolin							5	10			
Ga. (No. 27 & Velva) Kaolin						10	10	10	14		7
Ga. (Dawson) Kaolin										16.0	
Va. Moneta Spar	33.8	31.0	31.7		32	15	15	15	15		21
N.C. (Minpro) Spar				34		15		15	15	36.8	10
Canadian (Derry) Spar							15				
Penna. Va. Flint	19.6	23.0	21.8	20	24	20	20	20	20	17.2	20
TOTAL	100.0%	100.0%	100.0%	100%	100%	100%	100%	100%	100%	100.0%	100%
Date of Approval	Victor prior to 1926	4/4/38	Victor & Balto. 1928	4/4/38	3/18/40	10/7/45	2/7/47	8/10/49	10/15/50	4/15/46	3/6/52

Notes on Progress of Body Preparation

English Ball Clay Bodies - separate blunging of ball clays, 3000 lb. total batches ball milled.

Domestic Bodies prior to 1955, 6000 lb. blunger batches, $1\frac{1}{2}$ hr. blunging, 6 hrs. slip aging. Since 1955, 7500 lb. batches, blunged $1\frac{1}{2}$ hrs., no aging of slip.

Bodies Used For:

No. 110 - all line insulators
No. 128 - all ware, plunged, thrown
No. 124 - suspensions, switch & bus
No. 135 - pug & turn, some suspension insulators
No. 740-740-P - common body - slip mixing or "dry mixing"
789 - dry mixed only - hard pugmill extrusion on restrictive basis
740-1 - slip mixing only - all work

Table 11 - Schenectady Wet-Process Bodies (1925-1956)

	English Bodies				Domestic Bodies	
	1 1925-28	2 1929-30	3 1930-32	4 1932-38	5 1939-48	6 1949-56
English (Ivory Fat) ball clay	8%					
Bedminster (Dorset) ball clay		12.5%	22%			
No. 11 Dorset ball clay				27%		
Miss. M&D ball clay					13.5%	12.0%
Tenn. (Jernigan) ball clay	17	12.5	3			
Kentucky #4 or Royal ball clay					13.5	15.0
English China Clay*	20	25.0	25	23		
N.C. Kamec Kaolin					11.5	11.5
Ga. (#27 or Velva) Kaolin					11.5	11.5
Canadian (Derry) Feldspar	31	30.0	31	30		
N.H. (Puritan) Feldspar					1.0**	30.0
Me. (Oxford) Feldspar					30.0	
Flint (Pa. or Va.)	24	20.0	20	20	19.0	20.0
TOTAL	100%	100.0%	100%	100%	100.0%	100.0%

Note: These bodies contained only from 25 to 27% ball clay, which was the maximum amount required for making pug and turn apparatus bushings.

The Oxford, Maine feldspar was higher in free silica and 1% N.Y. Talc was added for better vitrification. The Royal ball clay was a blend of two Tennessee ball clays, i.e. Royal and Victoria. With English ball clays, the firing was cone 9-10, with domestic clays, the firing was 1 cone higher (cone 10-11).

*A-1 Hammill & Gillespie or No. 35 - Moore & Munger
**New York Talc

Chapter III. Wet-Process Bodies

History

Fred M. Locke, in his 1899 catalogue on High Insulation Line Material describes his insulators as "China Insulators", perhaps in the knowledge that the earlier insulators here and abroad, were produced from the same body compositions used for making porcelain dinnerware. With the ever increasing requirements in later years for much larger size insulators and with higher mechanical strength, the former, more fragile porcelain bodies had to be replaced with special bodies of better plasticity, and dry (unfired) strength and greater toughness after firing. This is the electrical porcelain as we know it today.

Body Ingredients USA and Abroad

Electrical porcelain in the U.S.A. and in England is produced from three basic materials: clay (45-50%) feldspar (25-30%) and flint (30-20%). In Central Europe, for instance, body compositions are made up, primarily for economic reasons, from some other ceramic raw material like Pegmatite, a mineral consisting of 42% quartz, 45% feldspar and 3% Kaolin. As an example, the writer worked with a high voltage porcelain body in Germany in the 1920's, consisting of 28.8% kaolin, 20.4% plastic fire clay, 45% pegmatite, 4.3% flint (quartz) and only 1.5% feldspar. The necessary feldspar flux and flint, of course, is contained in the rather coarse pegmatite mineral. Incidently the entire body had to be ground for hours in large ball mill to obtain the necessary fineness. The essential differences between American and English insulator bodies can be briefly stated as follows:

<u>American (English) Bodies</u>) High plastic, low sintering clay,
) high feldspar - low silica (flint)
) lower firing (cone 9-11)

<u>German Bodies</u> (Kaolin type and plastic siliceous clays,
(lower feldspar - higher silica (flint)
(higher firing (cone 14-15)

As far as the electrical and mechanical properties are concerned, there appears to be only little differences between American and German made porcelain. There are practically none of the low sintering, high plastic ball clays as found in the U.S. or England available in Germany. In general, their ceramic raw materials and body compositions are more refractory and require a higher firing to obtain complete vitirification.

As mentioned before, the correct proportioning of the body ingredients - clay-feldspar and flint, is not only important to good working properties, but has a great influence upon the mechanical and dielectric strength of a body. Some statements have been made in German literature that an increase in the amount of feldspar improves the dielectric strength, an increase in clay improves the thermal shock resistance, and an increase in flint improves the mechanical strength.

Proportioning of Raw Materials -

Effect Upon Mechanical Strength

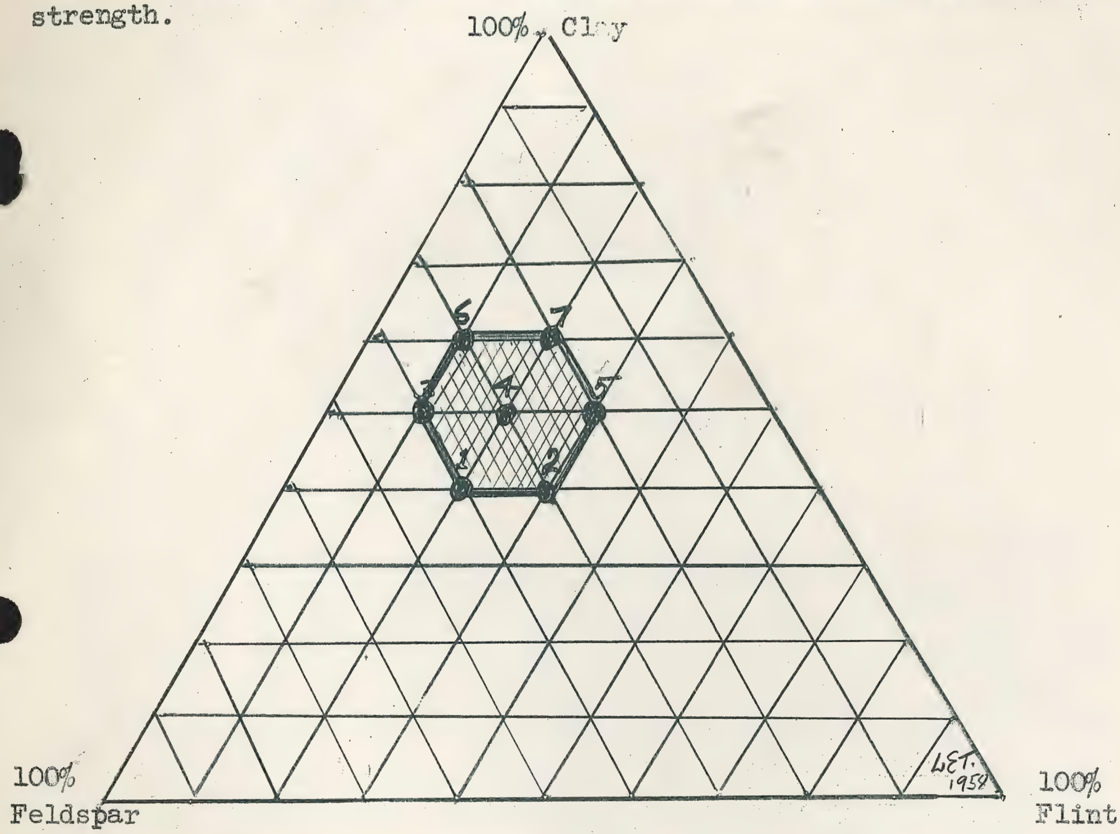


Figure 3 - Body Compositions
Variations in Flint Content - See Table 10

It has been found, however, that not all of these high dielectric and mechanical properties can be obtained in a single porcelain composition and, therefore, a compromise has been made in proportioning the raw materials in order to obtain some all-over good properties in the fired body.

The following body composition is typical for American electrical porcelain, ball clay and china clay 50%, feldspar 30%, flint 20%. It is now generally realized that high nechanical strength is the foremost requirement next to good dielectric strength. The question is then, can the mechanical strength in a fired body, by for instance, adding higher proportions of flint?

The following data concerning this subject is based on experimental work of a series of porcelain bodies containing from 10-30% flint and 20-40% feldspar and 40-60% ball clay and china clay. The bodies are also plotted in triaxial diagram Figure 3, each point representing a 100% mixture.

Table 10

	Body Compositions			Fired Transverse Strength (lb./psi)	
No.	Clay	Feldspar	Flint	Cone 9	Cone 11
1	40%	40%	20%	10,400	10,130
2	40	30	30	11,650	11,190
3	50	40	10	9,620	11,170
4	50	30	20	11,740	11,120
5	50	20	30	8,740*	8,840*
6	60	30	10	11,010	11,270
7	60	20	20	9,090*	11,230*

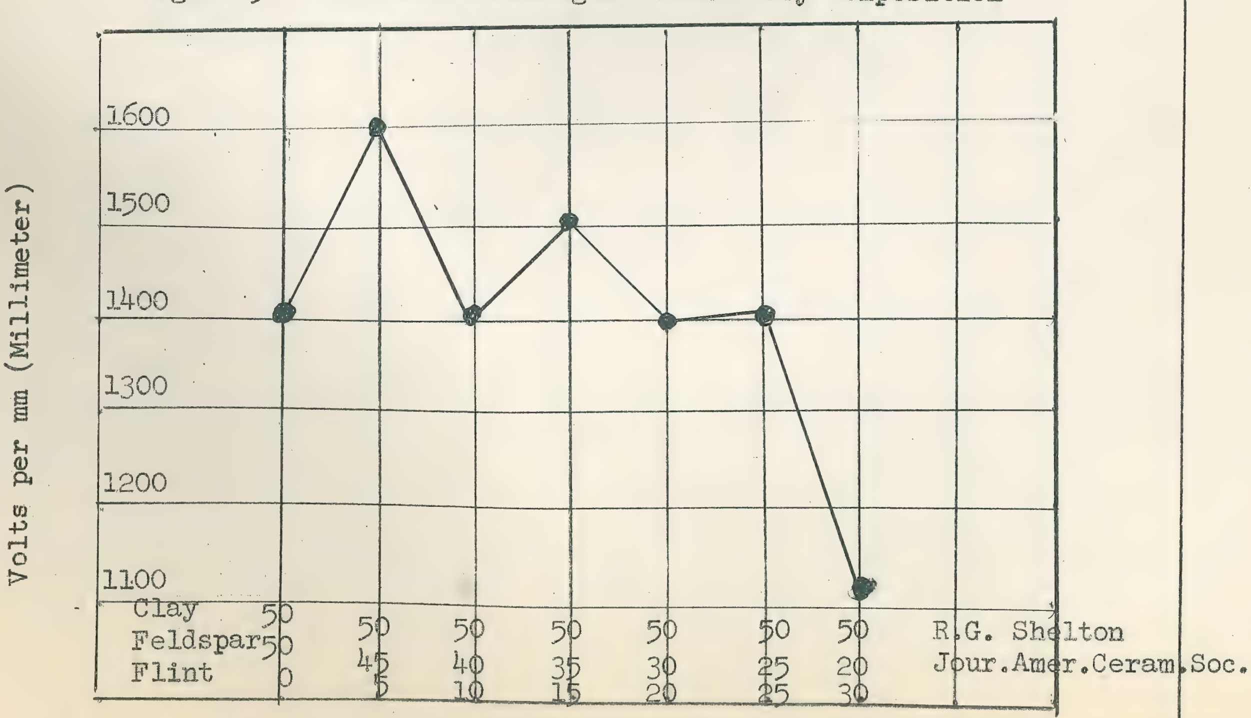
The lower strength in the bodies marked (*) are due to incomplete vitrification, i. e. porosity.

The results show that within the range of compositions studied there is no development of unusually higher strength by increasing the amount of flint over that contained in body No. 4 which is the typical American electrical porcelain body.

Of considerable interest is also the relation of composition to the dielectric strength of the fired porcelain. In Figure 5 the dielectric strength is plotted for seven (7) bodies in which the amounts offeldspar and flint are varied.

Effect Upon Dielectric Strength

Figure 5. Dielectric Strength Versus Bocy Composition



It is shown that with increasing amounts of feldspar, up to 45% and a reduction of flint the dielectric strength is increased. But as shown in the previous body series (Table 10) such higher feldspar bodies are lower in mechanical strength.

It is stated in one of the earlier Locke catalogues that "There is no secret in the manufacture of satisfactory insulators and that success depends much upon the selection and proportioning of the ingredients, the employment of proved practices and exact factory control". It is added also further that after the basic raw materials are selected that "The problem is now to get these various ingredients mixed in the proper percentages".

This, of course, leads directly to the subject of body compositions. About the kind and sources of raw materials in body formulas used, there still exists the same traditional secrecy in our industry today. This is true in foreign and as well as in domestic porcelain plants. It is also a fact that of the few body formulas published in the papers of the American and foreign Ceramic Societies, none represent actual body compositions employed by the manufacturing plants.

Baltimore and Schenectady Wet-Process Bodies

Baltimore Bodies - Past and Present

Up to the year 1939 two wet-process bodies were in use at Victor and at Baltimore. The older one was the English Body No. 110 for line ware, containing imported ball clays and china clays. Later, an American Body (No. 117) was added for making bushings. In 1938 another English body (No. 128) was in operation, together with the No. 124 domestic body. Suspension insulators, switch and bus types and pintype insulators were made from this domestic body up to 1944. The No. 135 domestic body was introduced in 1940 and used for throwing high top, columns and station posts and for pug and turn bushings.

In Table 1 , eleven wet-process bodies, used from 1926-1952 are shown, but there have been from 1940 on at least another 10 bodies for longer or shorter periods in operation. The question may well be in order, "Why so many body changes during these years?"

Reasons for Body Changes

In order to answer this question, lets analyze the characteristics of some of these bodies, because without such an analysis this list would be merely of historical and of little practical value.

a. English Bodies

Black English ball clays, containing considerable amount of lignite, had to be blunged and screened separately. The bodies were ball milled - 3000 lb. total batch - a slow and expensive way of body preparation. Blue core formation in fired body common.

b. Domestic Bodies

No. 135 contained a Maryland ball clay, varying considerably in composition and dry strength. High green losses due to chipping in turning.

No. 740 and modifications (740A, 740G) were good bodies, very close to Schenectady plastic body. These bodies were abandoned when the common method of wet-blunging-filterpressing was replaced by a "dry mixing" method, requiring pulverized (airfloated) clays, some of which, used in these bodies, were not available in this form. Substitutions were made, using much finer grained (Pioneer, Huber, etc.) china clays which produced higher dry losses.

Body No. 789, especially designed for "hard pug mill" extrusion, was an all-around poor body.

Body No. 740-P, prepared both by dry mixing as well as wet-process (blunger) methods, was high in dry losses. Due to the high amount of ball clay (the highest ever used in such bodies) 740-P had a very short and critical firing range. Bloated and porous ware was found regularily on the same tunnel kiln car.

The present (740-1) standard body has been in operation since early 1952 with entirely satisfactory ware making and firing performance.

Schenectady Wet-Process Bodies

Past and Present

From 1925 to 1956, the closing of Schenectady Porcelain Plant, only six (6) major body changes were made; the important change being the substitution of domestic for English ball clays and china clays. Changes in feldspars were due to the Canadian feldspar mines becoming exhausted. The body compositions are shown in Table No. 11. All are used for apparatus (pug and turn) porcelains, because no hot-plunged insulators, i.e. suspensions, switch shells or pintypes, were made at the Schenectady plant.

Raw Material Substitutions

Perhaps the interesting features of the Schenectady bodies is the trend over the years to increase the plasticity and dry strength by the use of larger amounts of fine grained, high plastic ball clays. This was due to the changed method from hand throwing to pugmill extrusions, also from wet-turning (leather hard) to dry-turning methods. A much higher dry strength is required for turning insulators in bone dry state. It is simply necessary to design a ceramic body for the work to be done. On the other hand it is somewhat difficult to operate a porcelain plant, making a great variety of large and small insulators, with only a single body composition.

A word of advise.

If, for some reason substitutions of china clay or ball clays become necessary, it is well to remember that long time manufacturing experience has shown that a combination of fine grained ball clays (English or domestic) and fine grained and plastic china clays, in a wet-process body,

will produce ware which is very difficult to dry. This long time experience was repeated again in a series of six (6) experimental (pilot shop) bodies made in 1952 (No. 632 etc.) containing plastic ball clays and 10-12% plastic fine grained Pioneer kaolin. Suspension insulators made from these bodies showed high manufacturing losses in the nature of drying and firing cracks, porosity and bloating (over-firing). It appears then, that for all-around good making requirements and a satisfactory firing range, a blend of plastic and fine grained ball clays and a coarser grained (North Carolina or English) china clay, are the best combination in a single, common wet-process body for all types of ware made in the plant.

Large Increase in Body Production with Improved Methods

In closing this chapter on G.E. (Baltimore and Schenectady bodies) it is interesting to note the considerable increase over the years in the daily production of plastic body delivered from the slip house. More efficient raw material handling, disintegrated (and moisture controlled) cleaner, ball clays, chemical treatment of body slip and generally improved methods have resulted in this increase in this plastic body production. As shown in Table 10 (Baltimore Bodies) the daily production in the two available 3000 lb. batch ball mills and filterpressing was approximately 50,000 lb. plastic body per 8 hour shift. Today, with 18-20 more simplified wet blunging methods, we can produce up to 150,000 lb. plastic body per shift.

Outside Manufacturers Body Compositions

Wet-Process Bodies - Outside Manufacturers

The following chapter will show what every manufacturer of high voltage porcelain has developed and uses in his own body composition, which he usually keeps a closely guarded secret. In spite of this, however, a number of body compositions, at least of those of our major competitors, have become known to us through various reliable sources. These compositions are of considerable interest because from such information we can compare our own performance in this field. We have, for instance, been able to duplicate on smaller scale* wet-process bodies used at the Ohio Brass and Lapp Insulator plants. We have made various types of insulators according to these body formulas and, thereby, obtain not only valuable information of the working performance, but also electrical and mechanical strengths data of the fired porcelains.

Wet-process body compositions, including a short discussion of their characteristics are presented of the first four listed competitors. In Table 12, body compositions of the other five insulator manufacturers are shown.

1. Lapp Insulator Corp., LeRoy, New York
2. Ohio Brass Company, Barberton, Ohio
3. Pinco Porcelain Insulator Corp., Lima, New York

*See Tech.Report LK-80-CR 12/4/52 and Ceramic Report 12/20/56.

4. Victor Insulator Inc., Victor, New York
5. Illinois Electric Porcelain Co., Macomb, Illinois
6. Hartford Faience Company, Hartford Connecticut
7. Porcelain Products, Parkersburg, West Virginia
8. Westinghouse Electric Manufacturing Company, Derry, Pa.

1. Lapp Insulator Corporation

Lapp Body

Two body compositions are known, No. 1 was used when Canadian feldspar was still available. The other (No. 2) contains New Hampshire spar. It is reported that Lapp also now purchases some North Carolina feldspar.

	Body No. 1	Body No. 2
M&M No. 149 English Ball Clay	14%	18%
*Tenn. (Bell) Universal Ball Clay	14	12
MWM English China Clay	19	18
Canadian (Genessa) Feldspar	33	-
New Hampshire-North Carolina Feldspar	-	32
Penna Flint	20	20
	100%	100%

*50% Dresden Ball Clay and
50% Dark Ball Clay

Chemical analyses of Lapp's raw (unfired) body and from section of a fired suspension insulators were made. From the unfired body analysis and, knowing the raw materials used at Lapp, the above body composition No. 2 was duplicated and verified again by chemical analysis of the duplicated body. In 1956, Lapp also was supplied with a cleaner, i.e. less ligneous clay known as Regal (Tenn.) ball clay as a substitute for the Bell ball clays. The basic composition, i.e. the use of English ball and English China clay has not been changed in more than twenty years.

The dry strength of the Lapp body varies between 575 and 600 lb./psi against that of 800 lb./psi of the G.E. No. 740-1 body.

2. Ohio Brass Company

Ohio Brass

The raw materials (English ball clay and English China clay) are supplied by the same importer (Moore & Munger) that supplies Lapp with these clays.

2. Ohio Brass (conti.)

Ohio Brass

O.B. Plastic Body

No. 149 English Ball Clay	14%
M&D Mississippi Ball Clay	5
No. 5 Dark Tenn. Ball Clay	10
MWM English China Clay	17
Keystone (SD) Feldspar	32
Penna. Flint	22
	100%

A raw (unfired sample) of the O.B. body was chemically analyzed. From this and the chemical analysis of the raw materials the O.B. body was duplicated with a very close check on the above raw body composition. This body, indidentally has a higher dry strength due to the presence of Mississippi and No. 5 Dark Tennessee ball clays. This O.B. body is very plastic and contains a substantial amount of organic, i.e. carbonaceous matter, which is not too favorable to fast firing. The entire production of large and smaller insulators is made from this single body.

The dry strength of the O.B. body is between 650 and 700 lb/psi.

3. Pinco Body

Pinco uses a so-called "soft", i.e. low dry strength body apparently well suited for making smaller types of insulators.

Pinco Body

Pinco Body

*No. 30 Royal Tenn. Ball Clay Blend (United Clay Mines Corp.)	33%
Kingsley (Ga.) China Clay	9
Layton (Ga.) China Clay	8
Potash (Consolidated) Feldspar	32
Penna. Flint	18
	100%

*No. 30 Ball Clay consists of: 1 part Victoria
1 part Stratton
1 part Rex
1 part Royal

3. Pinco Body (conti.)

The preparation of this body, as that of all others, is presented in a later chapter on "Body Preparation". The low dry strength of this body (685 lb. psi), would make this impractical for the production of large type bushings.

The Pinco body has been reproduced here on laboratory scale, showing fired mechanical strength on unglazed and glazed test cylinders equal to G.E. No. 740-1 standard body.

4. Victor Wet-Process Body

Victor manufactures electrical porcelain, advertised as "purified porcelain". The only purified raw material used in the body is de-mineralized water. At Victor the water is high in lime which they believe to be detrimental to good electrical properties.

Victor Wet-Process Body

Victoria (Tenn. Ball Clay)	12.5%
Kentucky Old Mine No. 4 Ball Clay	12.5
Kentucky Special (dark) Ball Clay	5.0
Ga. (Kingsley) China Clay	20.0
Potash Feldspar (N.H. and Va.)	30.0
Flint (Penna. and Va.)	20.0
	100.0%

This body has only a fair plasticity and low strength (about 600 lb. psi). Victor has experienced off and on firing trouble in spite of their narrow cross-section kilns. In dry-turning the body has a tendency to chip and shatter, making it necessary to employ slower speed in lathe operations.

Table 12

Wet-Process Bodies - Outside Manufacturers

Illinois Porcelain Company

New Ky. No. 4 Ball Clay	11%
Kentucky Special Ball Clay	11
English (A-1) China Clay	31
N. D. Feldspar	34
Total	100%

This is a very low strength and brittle body, not suited for making large type bushings. Illinois has had trouble with firing (porosity).

Porcelain Products Company

New No. 4 Ball Clay	28.5%
Pioneer (Ga.) Kaolin	16.5
N.C. Feldspar	37.75
Flint	19.25
Total	100.00%

*This N.C. feldspar is high in free silica, therefore, some of it is counted as flint in the body. The plastic, fine grained Georgia clay is to increase plasticity, but this is still a tender body.

Hartford Faience

M&M Dark English Ball Clay	28.2%
No. 17 English China Clay	19.0
Maine and Conn. Feldspar	33.0
Flint	16.6
Nepheline Syenite	3.2
Total	100.0%

The M&M ball clay is high in lignite and the body must be blunged and screened carefully to avoid bloating, blue core or pin spots in the fired ware. The flint content looks low, but both feldspars are high in free quartz (flint). O.B. and Lapp formerly used this dark ball clay but abandoned it years ago, substituting it with the cleaner No. 149 English ball clay.

Westinghouse Company (Derry Plant)

The Westinghouse Company has always used only domestic raw materials with the exception of English China Clay in the casting body.

Ky. No. 4 Ball Clay	12.5%
Ky. Dark Special Ball Clay	12.5
Georgia (Pioneer) Clay	21.0
N.C. or Va. Feldspar	32.0
Penna. Flint	22.0
	100.0%

This body is used for all plastic (hot pressed and soft pug and turn work). Formerly Westinghouse ground bodies in ball mill, but discontinued this practice 15 years ago.

Sufficient high strength for dry turning is obtained from Kentucky Dark ball clay and the fine grained, plastic Georgia clay.

An examination of the body compositions listed in the preceding pages permits certain conclusions, which will be presented here as follows:

a. It has been found practically impossible to establish a body composition by a mathematical formula which will include all the variables involved in producing a satisfactory porcelain body. Therefore, body compositions have been, and some are today, mostly the result of empirical methods of "trial and error" and of personal observation and experience. It is only in recent years with the advance in ceramic science and engineering that better selections and proportioning of raw materials in ceramic bodies are being applied.

b. Each of the manufacturers listed in preceding pages is operating with his own particular body composition, differing from plant to plant in the type and proportions of raw materials, particularly in ball clays and china clays. Since these bodies are often used without change for many years, one must assume that they are giving good results and tolerable manufacturing losses for the type of ware produced in the plant.

c. However, as pointed out in a short critical study added by the writer to each of the listed body compositions, some of these have certain short comings which tend to prevent best economical operations (making-drying-firing) or the production of the same high quality electrical porcelain made by the leaders in the industry. A well-designed body, consisting only of high-grade raw materials is important. After all an insulator can be no better than the porcelain from which it is made.

d. Some of these bodies, considered only the second best in their all-around properties, are the ones that contain dark, highly ligneous ball clays which, in spite of screening, carry too much fine lignite particles into the body, making for difficult and slower firing; low strength ball clays which do not permit fast dry lathe turning, and low grade (high silica) feldspar, which vary considerably in quality from time to time causing porosity trouble. Such objectionable raw materials are found in the bodycompositions of some of the "outside" insulator manufacturers. Perhaps, here, low raw material costs rather than quality has been the first consideration. Naturally, pre-selected materials cost more than the oridinary "run of mine" grades, but the premium leaders in the industry pay for them is insurance against failures and losses on the line.

G.E. Experience with English Ball Clay Bodies

<u>English Ball Clay Bodies</u>

In 1956 the Ceramic Engineering Section of the Insulator Department conducted an extensive investigation of wet-process bodies bearing English clays, which were exactly the same as used by Lapp and Ohio Brass Companies.

The wet-process bodies of both of these competitors were duplicated and run on limited factory production. The results showed no lower manufacturing losses in the various types of insulators made. The lower dry strength of both bodies made it necessary to slow down lathe operations to prevent chipping of the insulators. No improvements were noted in the fired strength of unglazed and glazed test specimens.

To satisfy higher dry strength requirements and to use presently used domestic, lower cost raw materials, another body (641-5) was run also on limited factory production.

Experimental Body 641-5

No. 149 English Ball Clay	10%
Victoria (Tenn.) Ball Clay	10
M&D Mississippi Ball Clay	10
N.C. Kaolin (Kamec)	10
No. 27 Ga. Kaolin	9
N.C. Feldspar	10
Virginia Feldspar	21
Flint	20
Total	100%

The loss records of this (supervised) factory trial run showed the following exceptional low:

	Dry	Fired	
Suspension Insulators	5.0%	3.0%	
Switch Shells	1.7%	1.8%	(79047)
	4.0%	8.0%	(79640)
Station Posts	1.1%	1.8%	
Transformer Bushings (pug & turn, soft mill)	5.0%	6.0%	(131A709)

The results of this investigation show that research and experimentation devoted to improvements in ceramic bodies to obtain lower losses are just as important as the development of improved manufacturing methods and processes. Research must be continuous in both directions to remain successful in this highly competitive insulator industry.

Ceramic Body Calculation

Body Calculation Empirical Vs. Scientific Methods

The most common method of expressing body compositions is to give the proportions by weight of raw materials in the batch. Batch formulas, however, are inadequate for the purpose of estimating the varieties and amounts of constituents in the fired product.

It has been recommended that, since the ceramic materials are nearly always oxides or compounds that can be expressed as combinations of oxides, to express body formulas in terms of:

RO - bases or fluxes - K_2O, Na_2O, CaO and MgO

R_2O_3 - "neutrals" or amphoteric oxides - Al_2O_3, Fe_2O_3, and

R_2O - Acid oxides - SiO_2, TiO_2

This calculation is based on the chemical analysis made either of a raw or fired body. By this procedure and simplified formula an easy comparison can be made in the amounts of fluxes and refractory oxides present in the various porcelain bodies.

During the past years we have obtained small samples of unfired wet-process bodies from the manufacturers listed below. Chemical analyses were made of these body specimens which are shown as follows:

Chemical Analyses

G.E. and Outside Manufacturers Porcelain Bodies

Manufacturer	#1	#2	#3	#4	#5	#6
SiO_2	65.66%	67.52%	67.20%	65.10%	66.69%	65.92%
Al_2O_3	22.26	20.50	20.14	21.94	21.10	20.97
Fe_2O_3	0.47	0.64	0.52	0.35	0.70	0.68
TiO_2	0.45	0.46	0.56	0.57	0.54	0.48
CaO	trace	0.24	0.35	0.32	0.25	0.30
MgO	0.24	0.06	0.31	0.13	0.14	0.28
K_2O	3.47	3.70	3.86	3.26	3.68	3.98
Na_2O	1.51	1.30	0.99	1.35	0.93	1.40
Ign.Loss	5.78	5.62	5.96	7.17	5.98	6.16
	99.84%	100.04%	99.89%	100.29%	100.01%	100.02%
Date of Sample	12/11/51	6/4/56	6/14/52	7/11/52	2/27/56	
Calculated) RO	5.52	5.70	5.84	5.38	5.33	6.39
Percentage) R_2O_3	24.20	22.32	22.08	23.97	23.15	23.03
Fired Basis) RO_2	70.28	71.98	72.08	70.65	71.52	70.58
	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%

#1 - Lapp Insulator Corp.
#2 - Ohio Brass Co.
#3 - Victor Insulator Corp.
#4 - Westinghouse Derry Plant
#5 - G.E. Baltimore 740-1 Body
#6 - G.E. Schenectady Body

The Schenectady body is highest in RO (fluxes) and insulators, i.e., apparatus porcelains were fired about $1\frac{1}{2}$ cone lower and at a longer cycle in the Dressler kiln.

Chemical analyses and calculations as presented here are of interest, but it must be clearly understood that without accurate information about the physical and chemical properties of the raw materials, especially the ball clays and china clays used in each of the six listed manufacturers, a duplication of their porcelain bodies on the sole basis of a chemical analysis is quite impossible.

Particle Size Distribution - Plastic Bodies

Grain Size Distribution

G.E. and Competitor Bodies

Compared

The workability of plastic bodies is directly influenced by the grain size of the raw materials, particularly by particles of 1 micron (μ) and smaller. Whereas the plastic ingredients, i.e. ball clays and china clays are naturally finely divided materials, needing only proper dispersion in water, the non-plastic body ingredients, feldspar and flint must be by mechanical crushing and grinding reduced to the fine particle sizes required by the porcelain industry. The importance and effects of such fineness upon working and firing properties has already been discussed in the chapter on "Feldspars and Flint."

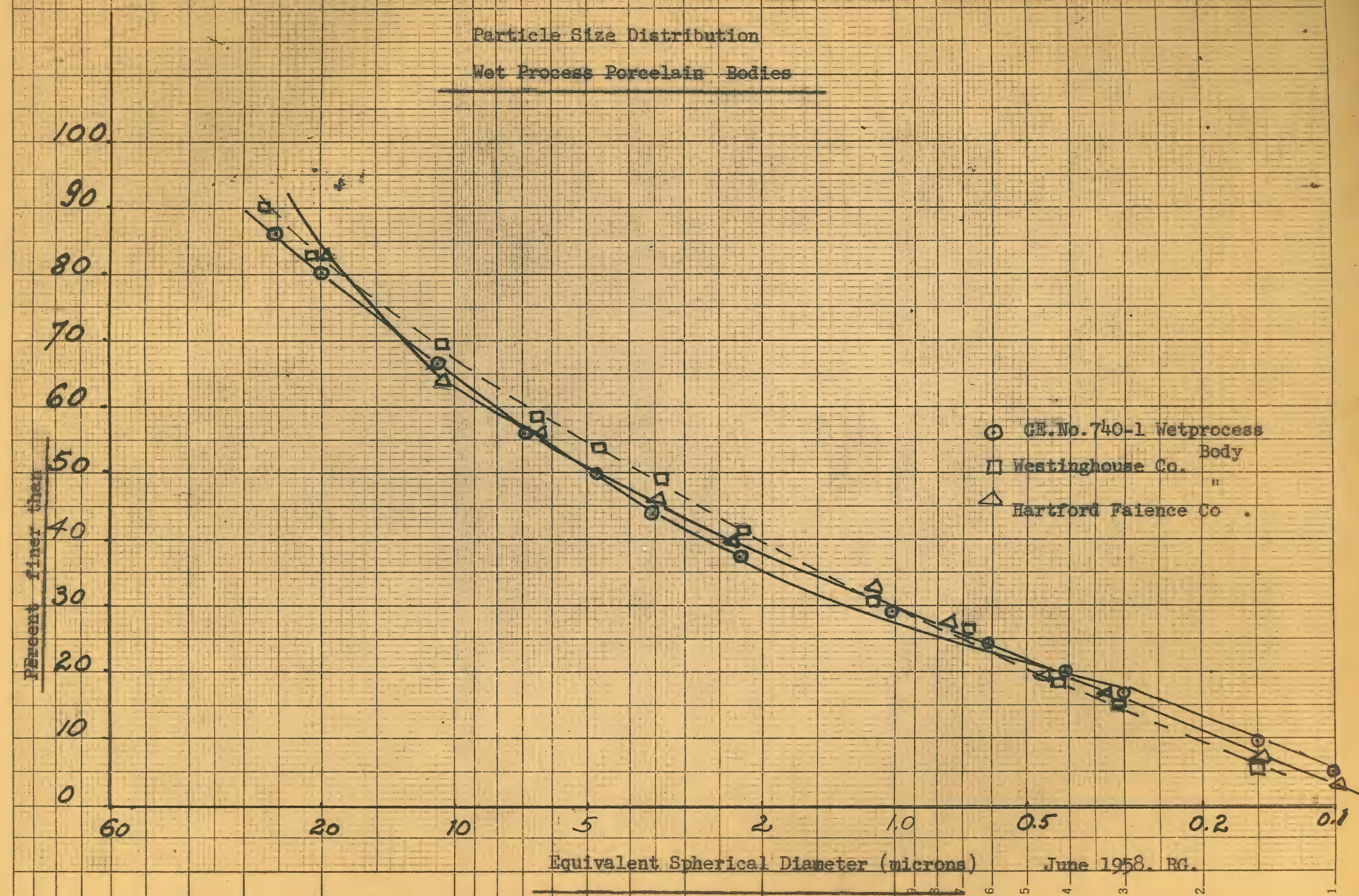
Information of the grain size distribution of wet-process insulator bodies is also of interest. A comparison of the grain size distribution of the G.E. 741-1 and that of several others was made possible by obtaining small samples of raw bodies from the following insulator manufacturers:

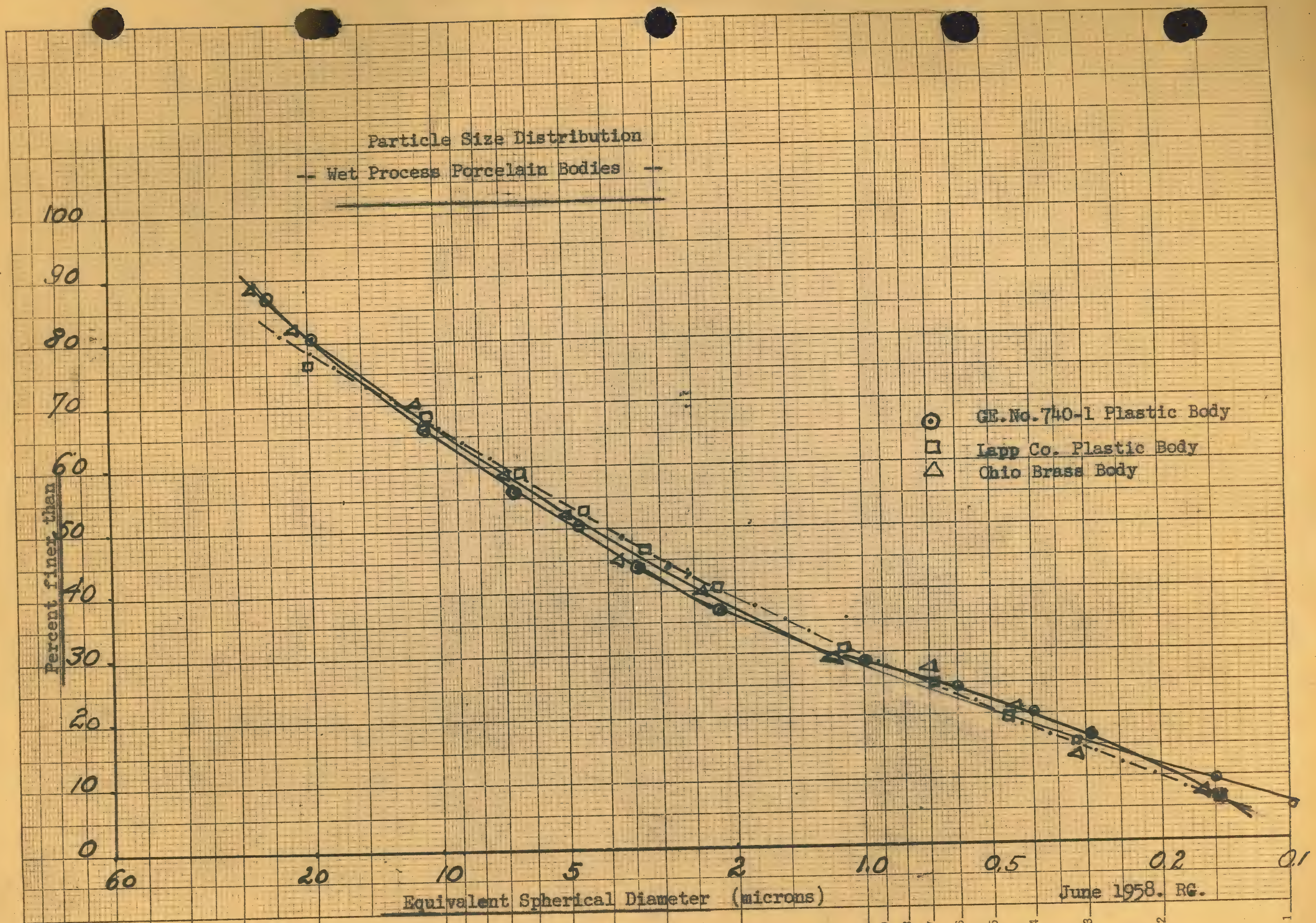
Ohio Brass Co.
Lapp Insulator Co.
Hartford Faience Co.
Westinghouse Electric Co.

Compositions of these bodies are given in previous chapter on "Body Compositions".

The results of subsieve particle size measurement made at our Ceramic Laboratory are shown on attached two diagrams. In spite of the fact that each of these insulator manufacturer uses different imported and domestic ball clays and china clays, there appears to be practically no difference in the amounts of coarser or finer particles in these bodies. It is of course known that each of these manufacturers now purchases feldspars and flints, which made up 50% of the body composition, to the same fineness (95% finer than 325 mesh sieve) and it appears that these non-plastic materials more than the clays, influence the total grain size distribution characteristics of the bodies.

The grain size distribution in casting bodies is generally of much greater importance. This will be discussed later in the following chapter on "Casting Bodies".


Particle Size Distribution
Wet Process Porcelain Bodies
GE.No.740-1 Wetprocess Body
Westinghouse Co. "
Hartford Faience Co.
Percent finer than
100
90
80
70
60
50
40
30
20
10
0
60
20
10
5
2
1.0
0.5
0.2
0.1
Equivalent Spherical Diameter (microns)
June 1958. RG.



Particle Size Distribution
-- Wet Process Porcelain Bodies --
GE.No.740-1 Plastic Body
Lapp Co. Plastic Body
Ohio Brass Body
Percent finer than
100
90
80
70
60
50
40
30
20
10
0
60
20
10
5
2
1.0
0.5
0.2
0.1
Equivalent Spherical Diameter (microns)
June 1958. RG.

Chapter IV - Wet-Process Body Preparation and Processing

Every manufacturer of high voltage insulators today stress the importance and the necessity of rigid process control to maintain low losses and consistently a high quality product.

Body Preparation

Process Control

It has justly been said that some of the manufacturing losses in this line of work have their start in the "Slip House". Any laxity in or non-observance of established good control methods usually set up a chain reaction from ware making to the fired product. To name just a few examples which may lead to difficulties and losses in the plant:

a. An unobserved hole in the Sweco slip screen will permit a substantial amount of coarse lignite particles and other foreign matter to pass into the plastic body. This will cause burn outs, holes or blisters in the body and pin-spots in the glaze. Low puncture values of the fired porcelain may be the result.

b. Omitting the specified amount or adding an excess of acid or salt (flocculant) to the slip slows down filterpressing, causes segregation in the filter cakes or, in the case of an excessive addition of these chemicals the over flocculation produced thereby will destroy the plasticity of the body. The result is drying cracks in the molded insulators.

c. Another, and certainly not uncommon trouble arises from worn-out filter cloths, causing blow-outs at the presses and soft and hard areas in the filtercakes.

The answer to how to avoid such troubles simply lies in correct supervision, good maintenance of equipment and strict observation of instructions issued by the process control engineer.

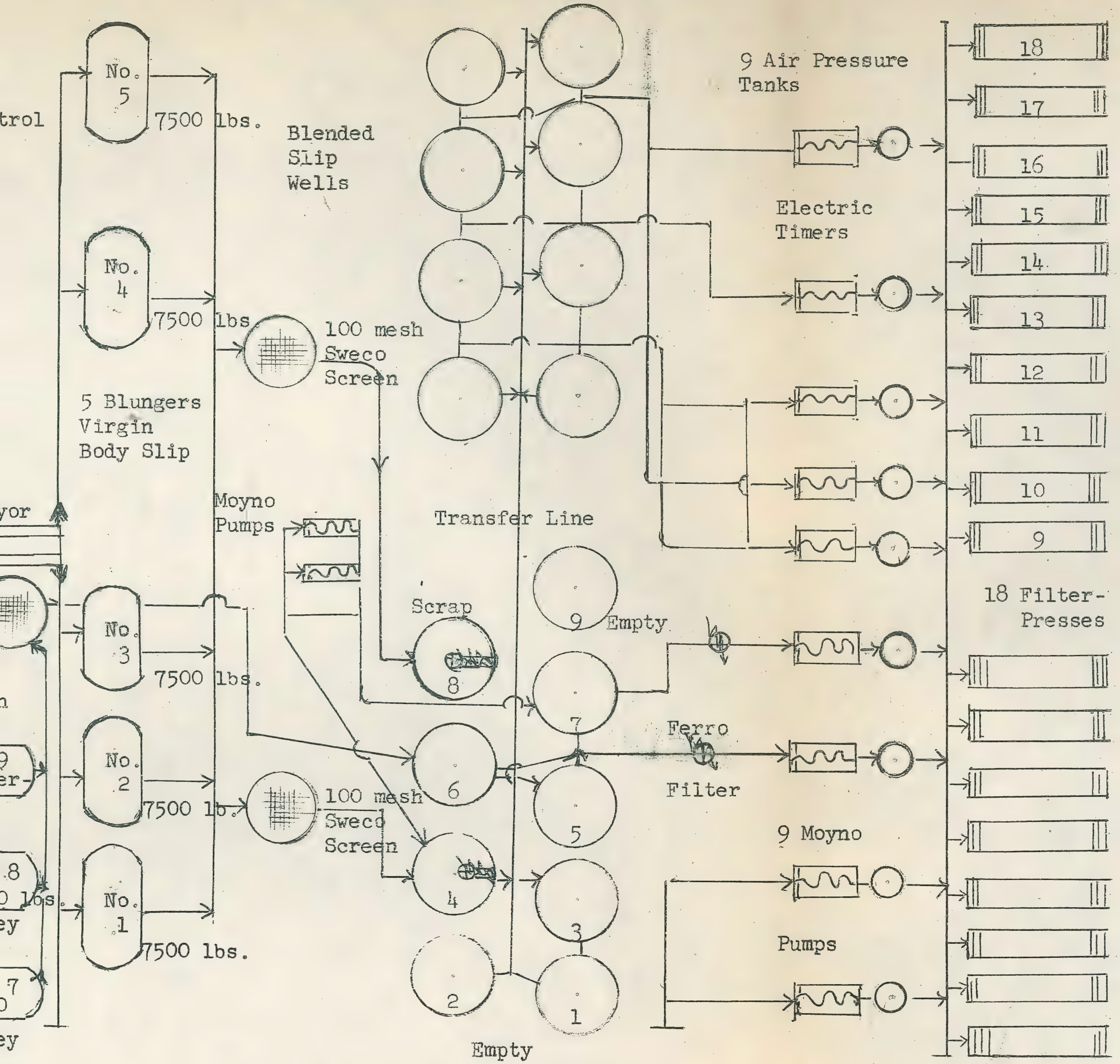
It is of considerable interest to compare the type of equipment and methods of body preparation employed at our G.E. Insulator Department with that of other insulator manufacturers.

Essential steps in the preparation of wet process bodies at the G.E. Insulator Department and at the Illinois Porcelain Company are illustrated here by two flow charts. These also include the control test performed from the raw materials to the filterpressed body.

Slip House Equipment and Methods - G.E. and Competitor Plants

Table 13 contains detailed information of the available slip house equipment and various methods employed in the process of plastic body preparation by seven porcelain insulator plants.

G.E. PLASTIC BODY - SLIP HOUSE LAYOUT



Material and Process Control

Moisture in Raw Materials

Daily check and scales corrected

Wet-Process Slip Checks

Specific Gravity and Viscosity
Chemical treatment of final slip

Filterpressing

Timed for various body consistencies

Daily Production

150,000 lbs. plastic body (dry material basis)

, 9 and 11 hold
terials for casting

No. 5, 6 and 7 scrap wells

Filterpresses hold
85 plates

Sept. 1958

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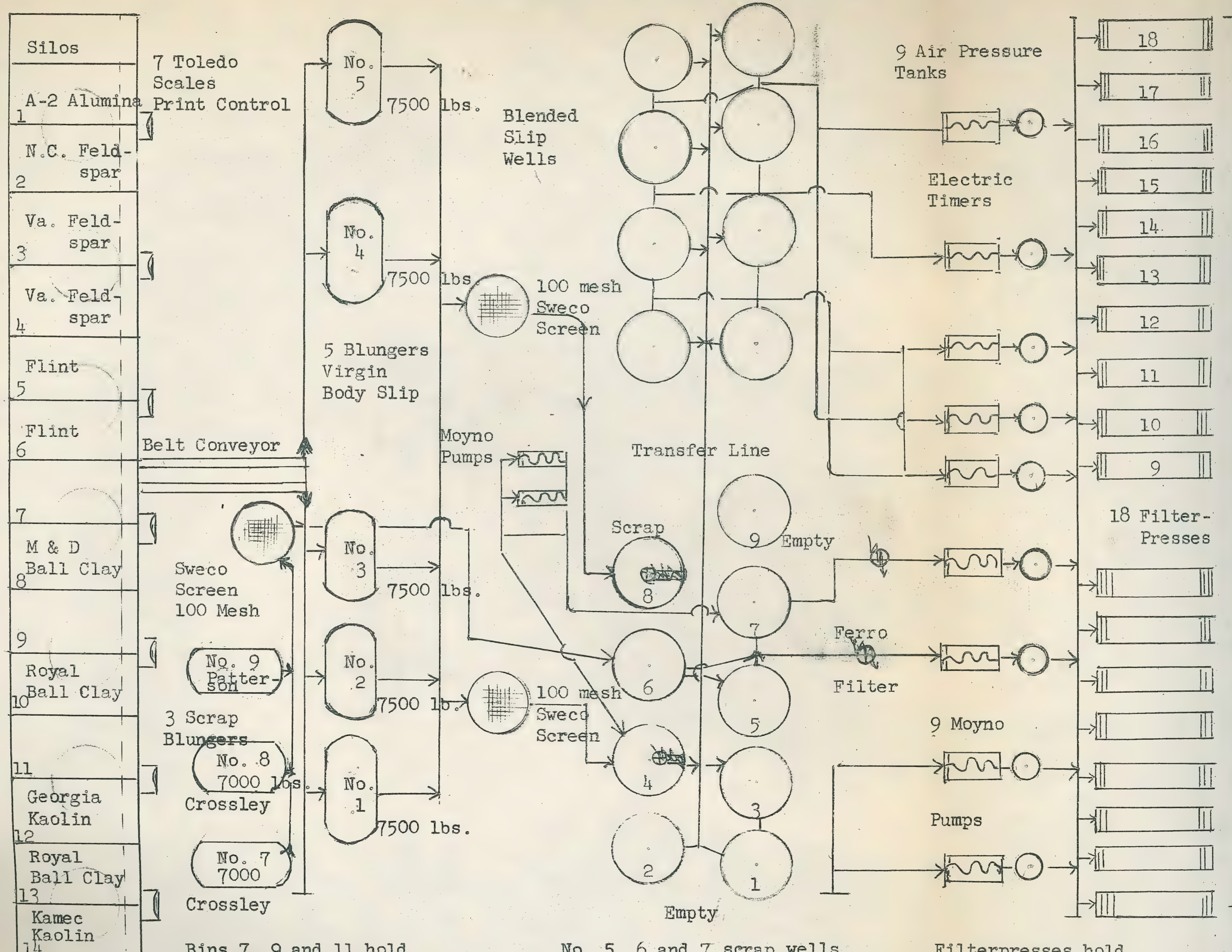
G.E. PLASTIC BODY - SLIP HOUSE LAYOUT



Bins 7, 9 and 11 hold raw materials for casting body.

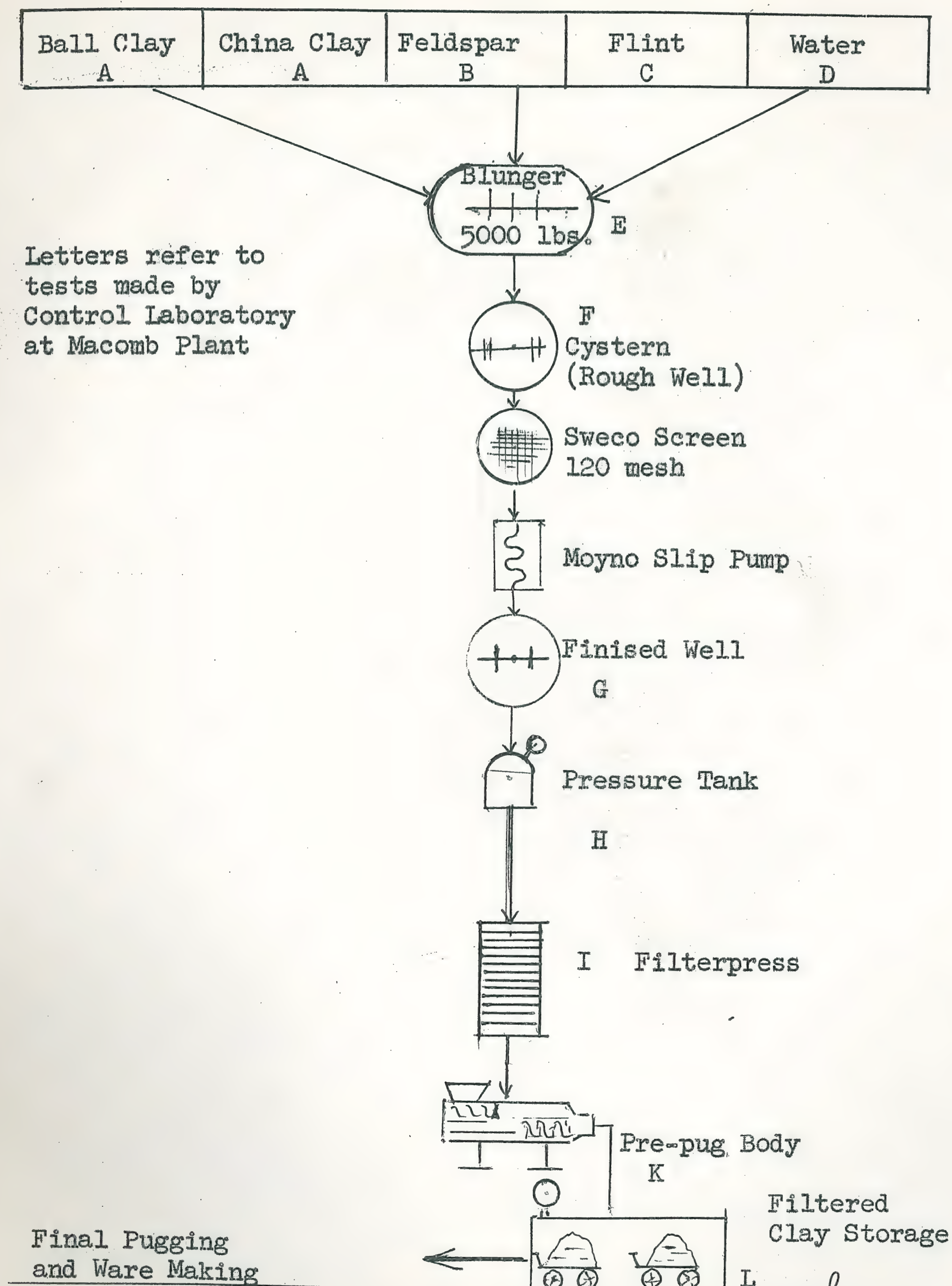
No. 5, 6 and 7 scrap wells

Filterpresses hold 85 plates

-To Page 35-

Wet-Process Body Preparation, Illinois Porcelain Company

Raw Materials and Body Composition Described on Page 29



Material & Process Control:

A. Moisture Check and Scale Adjustment

B. Screen Test 140-325 Mesh, Fusion Test

C. Screen Test - Sub-sieve Particle Size Analysis

D. Water pH Analysis Distilled Water

E. First Specific Gravity Adjustment

F. Screen Test for Residue and Impurities

G. Final Slip Adjustment
   Specifid Gravity
   pH Control

H. Automatic Timing of Filterpressing Pressure Control.

I. Stiffness Control Filterpressed Clay by Penetrometer Gauge

K. Pre-pugging All Filterpressed Clay

L. Body Storage Humidity Control

Note: Plastic body preparation differs very little from that at Baltimore. Illinois Co. pre-pugged all filterpressed clay and put it in storage before use. Baltimore stores this clay as filtercakes. The routine consistency check at the presses with penetrometer and reclassification into soft, medium and stiff clay permits proper storage and readjustment of time and pressure if need be.

Table No. 13 - Survey of Body Preparation Methods and Equipment

mber of ungers d Make	Size Dry Batch	Blunging Time Total	Type of Screen and Mesh	Slip Control Data, Specific Gravity, Chemical Treatment	Filter Presses Number and Type	Pressure and Time	Control Methods Employed
atterson	7,500 lb.	1½ hrs.	Sweco 100 mesh	1.40-1.42 110°F, pH 5.9-6.2 0.05% $AlCl_3$	16 total 12 Crossley 4 Patterson 80-85 leaf	90-110 lb./psi 90-120 min.	See flow sheet, MSN Instructions
rossley	8,400 lb.	2 hrs.	Sweco 100 mesh	1.40-1.45 90-110°F $AlCl_3$ as needed	5 Crossley 57 sq. leaf	110-120 lb./psi 90-120 min.	As per Manufacturing instructions 6/20/51
atterson	6,000 lb.	1½ hrs.	Sweco 120 mesh	1.50, pH 5.6 vacuum treated slip	6 Patterson round leaf	80-100 lb./psi 120 min.	Unknown. Titration test on clays.
ake unknown	4,000 lb.	2 hrs.	Sweco 120 mesh	pH 6.0-6.1 HCl added	13 Patterson round leaf	110 lb./psi 120 min.	Viscosity and specific gravity checks.
ecirculating ew round ottom style	10,000 lb.	75 min.	Sweco 120 mesh	1.50, 96°F Epsom Salt and NaCl	16 Crossley 72 round leaf	120 lb./psi 45 min.+ (soft clay)	Viscosity and specific gravity checks.
ake unknown	5,000 lb.	3 hrs.	Sweco 120 mesh	120°F Epsom Salt as needed	6 Patterson 72 round leaf	90-110 lb./psi 1-3/4 to 2-1/2 hrs.	See flow sheet.
ake unknown	7,600 lb.	2 hrs.	Sweco 100/140 mesh	1.41, 86° Be' $AlCl_3$ as needed	Patterson round leaf	110 lb./psi 1 hr. 45 min.	Unknown.

filterpressing varies with the requirements for soft, medium or stiff consistency clay.
rom 75 minutes to 3 hours (Ohio Brass-see note below).
Lapp, all other factories add some kind of chemical or chemicals to flocculate the slip
ng.

ll clays separately and screen this ball clay slip through 100-150 mesh screen.

r two inter-connected presses to 45 minutes pressing after the presses are
iquid slip. This would make a total minimum of about 90 minutes.

Table No. 13 - Survey of Body Preparation Methods and Equipment

Manufacturer	Number of Blungers and Make	Size Dry Batch	Blunging Time Total	Type of Screen and Mesh	Slip Control Data, Specific Gravity, Chemical Treatment	Filter Presses Number and Type	Pressure an[d] Time
G.E. Baltimore Plant	5 Patterson	7,500 lb.	1½ hrs.	Sweco 100 mesh	1.40-1.42 110°F, pH 5.9-6.2 0.05% $AlCl_3$	16 total 12 Crossley 4 Patterson 80-85 leaf	90-110 lb./ 90-120 min.
[G].E. Schenectady	2 Crossley	8,400 lb.	2 hrs.	Sweco 100 mesh	1.40-1.45 90-110°F $AlCl_3$ as needed	5 Crossley 57 sq. leaf	110-120 lb./ 90-120 min.
Lapp Insulator Co.*	4 Patterson	6,000 lb.	1½ hrs.	Sweco 120 mesh	1.50, pH 5.6 vacuum treated slip	6 Patterson round leaf	80-100 lb./ 120 min.
Victor Insulator Co.	6 make unknown	4,000 lb.	2 hrs.	Sweco 120 mesh	pH 6.0-6.1 HCl added	13 Patterson round leaf	110 lb./psi 120 min.
Ohio Brass Company	2 recirculating 2 new round bottom style	10,000 lb.	75 min.	Sweco 120 mesh	1.50, 96°F Epsom Salt and NaCl	16 Crossley 72 round leaf	120 lb./psi 45 min.+ (soft cla[y])
[I]llinois Porcelain Co.	6 make unknown	5,000 lb.	3 hrs.	Sweco 120 mesh	120°F Epsom Salt as needed	6 Patterson 72 round leaf	90-110 lb./ 1-3/4 to 2-1/[..] hrs.
Pinco Insulator Co.	2 make unknown	7,600 lb.	2 hrs.	Sweco 100/140 mesh	1.41, 86° Be' $AlCl_3$ as needed	Patterson round leaf	110 lb./psi 1 hr. 45 mi[n].

NOTE: Pressure and time for filterpressing varies with the requirements for soft, medium or stiff consistency clay.
Blunging time varies from 75 minutes to 3 hours (Ohio Brass-see note below).
With the exception of Lapp, all other factories add some kind of chemical or chemicals to flocculate the slip before filterpressing.

*Lapp and Victor blunge ball clays separately and screen this ball clay slip through 100-150 mesh screen.

+Ohio Brass set timers for two inter-connected presses to 45 minutes pressing after the presses are completely filled with liquid slip. This would make a total minimum of about 90 minutes.

A discussion of some of these methods and processes follows. Such a discussion is important in order to understand and evaluate the changes and progress that have occurred in the insulator industry during the past thirty years.

1. Ball Milling Body Slip

Grinding Body Slip

Up to about 15 years ago most porcelain manufacturers, including Victor and Baltimore, were grinding the body slip in large ball mills for one to three hours to obtain a desired fineness, especially in the feldspar and flint. These non-plastic materials were then only supplied at a fineness of 80% to 90% through the 325 mesh sieve. After the porcelain industry finally succeeded in their efforts to obtain finer ground feldspar and flint (now 95% finer than 325 mesh) ball mill grinding of the body slip was abandoned by practically every insulator manufacturer. Today, only Westinghouse at the Derry plant continues to prepare their casting slip by this ball mill grinding process.

2. Pre-Blunging (Washing) Ball Clays

Washing Ball Clays

Separately

The process of separately blunging and screening ball clays was originated first by Locke at Victor many years ago. It was employed also here at Baltimore until about 1940. The purpose of this rather slow and costly process is to remove as much as possible the coarser lignite particles and other impurities present in the crude ball clays. Today, only Lapp and the Victor Insulator Company (the latter still using the original Locke equipment) blunge and screen the ball clays before they are mixed with the other body ingredients. At Schenectady a much cleaner and less ligneous variety of English and later domestic ball clays were used, making pre-blunging unnecessary.

Although Ohio Brass and the Lapp Company both use the same dark variety of English ball clay, no separate blunging of the ball clays has ever been done at the O.B. plant. The question is then, does this pre-blunging (washing) of the ball clays produce a better porcelain, i.e. with less specks and pores that might be left from the burned-out organic lignite particles? The answer is that with the greatly improved, more efficient screening of the modern Sweco equipment, today most of the lignite and dirt is removed from the slip. Now, only a small amount of the fine carbon from the lignite of the ball clays, which no amount of washing and screening can entirely eliminate, goes into the body.

Microscopic examination of porcelain sections cut from Lapp, Ohio Brass, Victor and G.E. insulators made by the writer, showed practically no difference in quality between porcelain bodies made from pre-blunged (washed) ball clays and bodies containing crude ball clays added without previous refining. These microscopic examinations have also shown that all fired porcelains (including Lapp's) contain a certain amount of small size, closed pores, i.e. residual air voids. As a matter of fact bone dry porcelain before firing contains about 30% by volume of air voids, which are practically all closed during the vitrification period in the porcelain firing.

3. Lapp Vacuum Process

De-Airing

Body Slip

The Lapp slip de-airing process was patented in 1925. In this operation, instead of pumping the liquid body slip from the storage wells directly into the filterpresses, as is customary throughout the industry, the slip passes through a high vacuum tank where it is immediately brought to a boiling point and the air removed.

This process, still in use at Lapp today, is also used by the Canadian Porcelain Company at Hamilton. The Schenectady Porcelain Plant in 1931 built and operated on production basis such as Lapp equipment. Later, with no special benefit derived from this de-airing slip treatment, abandoned it in 1932. Westinghouse at Derry reported similar negative results.

It is well to remember that the Lapp slip de-airing process was developed before the present vacuum pugmills came into existence. It is reported that the Canadian Porcelain Company still operates with the old (vertical) non-vacuum pugmills, which is perhaps the primary reason for their still using the Lapp slip de-airing system. Since 1934 modern horizontal vacuum pugmills are used in the industry. They are more practical and efficient in removing air from the plastic body during the extrusion of insulator shapes. Therefore, the Lapp slip de-airing process must be considered an obsolete process.

A vacuum treatment of heavy casting slip applied prior to filling the plaster molds has been applied at some of the Schenectady cast insulators with various beneficial results.

4. Chemical Treatment of Wet-Process Slip

Chemical Slip

Treatment

pH Control

The advantages of chemical slip treatment and pH control of the porcelain body slip is well recognized in the industry and practically all insulator plants listed in Table 13 add acids or salts to the slip before filter-pressing. These chemical additions may be in the form of

$CaCl_2$, $AlCl_3$, $MgSO_4$ (Epsom Salt) or NaCl, HCl, or acetic acid. Added in small amounts they speed up filterpressing and prevent segregation of the feldspar and flint in filter cakes. The Baltimore plant first, about 20 years ago, added hydrochloric acid (HCl) but this caused eventual rusting of the blunger equipment and the acid was replaced with sodium chloride (NaCl). Then, later, following the Schenectady plant's experience with aluminum chloride ($AlCl_3$), this chemical is now used as a means of correcting variations in viscosity and pH, and as a very effective aid in faster filterpressing of the plastic body. Excessive amounts cause over-flocculation (large flocs) which destroys the plasticity of the body. Omitting aluminum chloride greatly slows down filtration and gives soft, mushy cakes. Much larger additions are necessary in the case of sodium chloride and Epsom salt. Best pH range in chemically treated wet-process slip was found by nearly all manufacturers to be between 5.8 and 6.2 (slightly acid).

5. Pre-Pugging and Clay Storage

Pre-Pugging and Clay Storage

It must be realized that in spite of chemical slip treatment, pressure and time controls, the plastic body in the form of filter cakes is not as uniform in consistency as would be desirable. Perhaps in full realization of these factors the Illinois Porcelain Company, as the only one plant known, pre-pugs all filter cakes and stores the pugged clay in humidity controlled storage rooms. This process is, however, not new. About 20 years ago the Schenectady plant pre-pugged and stored all clay for shorter or longer periods. It was then the experience that by this pre-pugging a greater uniformity in consistency and freedom from air in the plastic body was obtained.

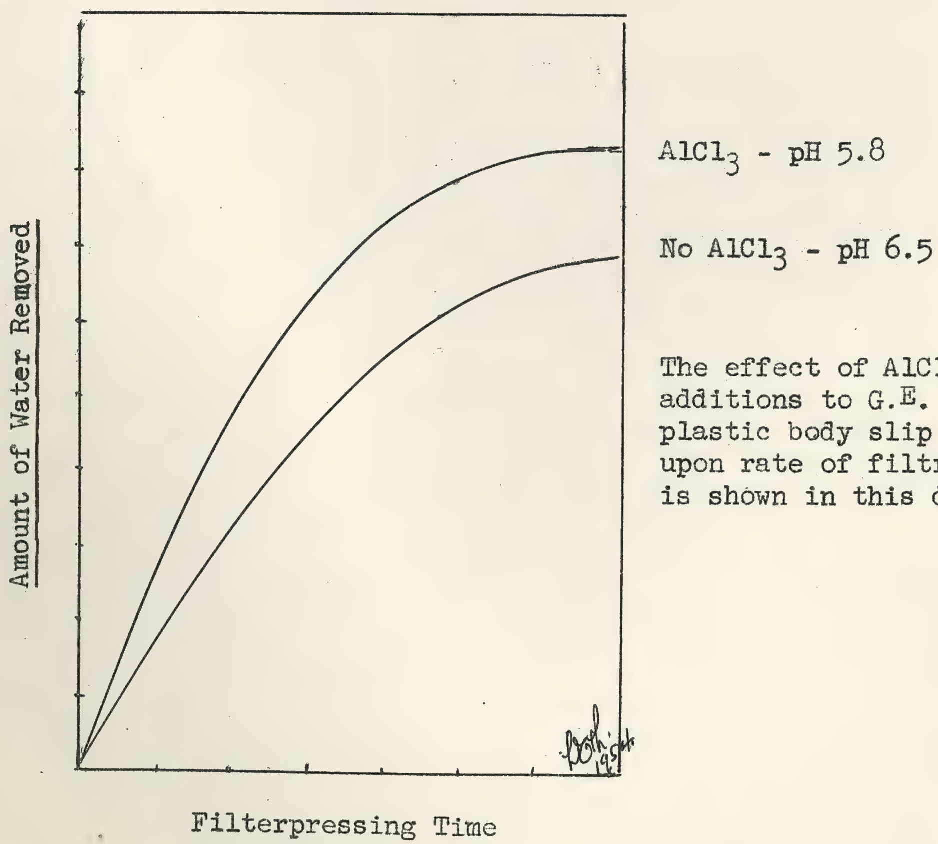
With the advent of the de-airing (vacuum) pugmill and discontinuance of hand throwing methods of forming insulator blanks, prepugging and aging of the body was abandoned. For most of the ware produced today, pre-pugging would only be an additional expense without extra benefits derived from this operation.

However, recently made extensive trials made here at Baltimore showed that seven items out of ten showed lower losses in either unfired or fired bushings. The higher losses were undoubtedly caused by pugging the blanks from filtercakes of non-uniform consistency.

As a second phase of this experimental work, the pre-pugging of the filterpressed body was done to increase the stiffness of the clay, so that the largest diameter hollow blanks could be extruded without collapsing or distortion. No clay directly from the filterpresses is ever stiff enough for the successful extrusion of large diameter insulator blanks. The manufacturing losses of the insulators made from this pre-pugging were also reported to be lower than those made from single pugging.

G.E. Experience with Pre-Pugged Clay

With the growing demands for porcelain bushings of ever increasing dimensions, more research in the field of chemical slip conditioning and more efficient filtration of the plastic body is quite evident.



The effect of $AlCl_3$ additions to G.E. plastic body slip upon rate of filtration is shown in this diagram.

Chapter V - Casting Bodies

Although the method of casting ceramic ware in plaster of Paris molds has been known for more than a hundred years, the casting of large insulators in this country had its beginning about 40 years ago. The G.E. Schenectady Porcelain Plant did much of the pioneering in the casting of large sectional, glaze-joined porcelain bushings.

Casting Bodies

Raw Material

Control

Perhaps more technical papers have been written on the subject of casting bodies and casting methods than on any other subject of forming ceramic ware. This is easily understood when we look upon the complexity and multitude of factors connected with this work.

The proper selection of suitable, fast casting ball clays and china clays, the control of specific gravity, temperature, fluidity (viscosity) and general casting behavior of the slip, all are important factors that determine success or failure in this type of work.

Long years of experience in this field with casting of large and small insulator shapes have shown this writer that, all other factors being equal, the percentage of grains in clays finer than 1 micron (d) has the greatest effect upon the casting rate of a body slip.

1. Ball Clays

Role of Ball Clay

There are only a few domestic and practically no foreign ball clays available for casting large, thick-wall porcelain pieces. The non-existence of such suitable ball clays is one of the reasons why large insulator shapes in Europe are still made by plastic molding and slip-joining methods.

The role of a ball clay in casting bodies is to supply fluidity and dry strength. Unfortunately, the fast-casting, coarse-grained ball clays have a low dry strength and a certain amount of a finer grained and stronger ball clay must be added to the body. Only dark colored, or black ball clays, containing a high concentration of organic matter, which act as a protective colloid and which prevents gelling of the slip, are suitable in casting bodies. Such ball clays, however, should not, as often offered by the clay producers, be purchased in pulverized (air floated) form, as the lignite is so finely sub-divided that it passes through the finest factory screens directly into the casting slip. A discussion of these, often very troublesome phenomena, is presented in a chapter on "Casting Methods".

Table No. 14

Ball Clays Used in Commercial Casting Bodies

1. Chemical Analysis	Bandy	No. 817*	Lamkin	Martin No. 5
SiO_2	60.74%	51.64%	57.14%	60.72%
Al_2O_3	24.30	30.26	28.47	25.53
Fe_2O_3	0.85	0.77	1.55	0.74
TiO_2	1.29	1.64	1.65	1.39
CaO	0.16	0.26	0.28	0.08
MgO	0.21	0.21	0.62	trace
K_2O	1.66	1.36	1.64 (K_2O + Na_2O)	1.72
Na_2O	0.43	0.24		0.40
Ign. Loss	9.82	13.75	8.78	9.35
Total Percent	99.56	100.13%	100.13%	99.93%
2. Physical Properties	Silceous clay - blackish-brown color. High in organic matter, fast casting rate.	*Blend of Old Mine No. 4 and Ky. Special. Brown color. Very slow cast. Used for high strength.	Blackish-brown, organic matter present. Fast casting.	Silceous-brown color, very fast casting, low shrinkage.
3. Dry Strength 50 Clay - 50 Flint	346 lb./psi	730 lb./psi	326 lb./psi	276 lb./psi
4. Absorption Cone 10 100% Clay	3.54%	2.10%	7.0%	3.92%
5. Mineral (DTA) and X-Ray Diffraction	Kaolinite major Illite present Organic matter	8-10% quartz. Kaolinite major Illite minor -no Montmorillonite	not available	not available
6. Grain Size (see attached grain size distribution graph)	Coarse grained	Fine grained	Coarse grained	

Four ball clays, widely used in casting electrical and sanitary porcelains, are listed and described in Table 14.

2. China Clay (Kaolin)

The proper selection and proportioning of china clay in a casting body is also very important. Fine grained Florida clay and Georgia clays are not suitable for casting heavy cross-section pieces. The Schenectady casting body contained coarser grained N.C. (Kamec) and Georgia kaolins, but in former years English china clay was used in Schenectady.

English China Clays

Preferred

Baltimore and Westinghouse, the only others engaged in the casting of large insulator shapes, always used only English china clay.

Experience with domestic china clays has shown that in spite of all control methods employed, variations in casting rate and losses were greater than with English china clays. Perhaps variations in grain shape has influenced the results. The N.C. (Kamec) clay has varied from time to time in the amounts of halloysite (rod-shape grains) and kaolinite (plate-like grains). These clay minerals tend to cast up a body with a different oriented texture, however, very little experimental work has been done in this field.

English china clays are also perhaps preferred by the industry for the reason that they contain a certain amount of ($KAlSiO_2$) fluxes in the form of very fine muscrovite mica which promote vitrification in the fired cast ware.

A detailed description of the English china clay (MWM) used in the G.E. casting body, is given on Page 11 and in Table No. 9 of this volume.

The question, how to design a satisfactory casting body for large and small pieces can be answered as follows:

Use a coarse-grained china clay with ball clays having a high concentration of organic matter. Such combination will require only a minimum of electrolytes for good fluidity and the slip will have a low water retention, resulting in a fast, solid cast.

In the attached Tables No's. 15 and 16 are listed past and present Baltimore and Schenectady casting bodies. In Table No. 17 the body compositions of three competitors are given. The Westinghouse body is of special interest, as it contains only 8% of ball clay. In order to obtain the most benefit from this black clay, the body slip is prepared (wet-ground) in large ball mills. The "W" Company produces very large bushings by pressure casting, described in a later chapter on "Casting Methods".

Table 15

CASTING BODY COMPOSITIONS

Listed here are only the three major body changes.

Baltimore Porcelain Plant

1
1934-1945

Jernigan (Tenn.) Ball Clay	12.5%
No. 817 Kentucky Ball Clay*	10.0
A-1 English China Clay	25.0
N.C. Minpro Feldspar	30.5
Flint	22.0
	100.0%

Reason for Body Change: The supply of Jernigan ball clay became depleted and a new ball clay "Bandy" from a nearby mine was substituted. Minpro Feldspar increased in free quartz content, therefore, more must be added resulting in body change No: 2.

2
1947

Bandy Black Ball Clay	12.50%
No. 817 Ky. Ball Clay	11.25
A-1 China Clay	22.50
N.C. Minpro Feldspar	32.75
Flint	21.00
	100.00%

Minpro Feldspar supply depleted, use of two feldspars, lower cost. No. 817 ball clay consists of No. 4 and Ky. Special ball clay from new deposits, resulting in body change No. 3.

3
1957 to Date

Bandy Black Ball Clay	12.50%
No. 817 Ky. Ball Clay	12.75
MWM Engl. China Clay	21.25
N.C. "Celo" Feldspar	16.25
Va. Moneta Feldspar	16.25
Flint	21.00
	100.00%

Body has improved plasticity and strength. MWM English China clay gives better casting range.

P.S. In 1934 the Locke casting slip was prepared by blunging the ball clay separately with soda and water, then grinding the body in a large ball mill for 5 hours.

* No. 817 Ky. Ball Clay consists of a blend of 50% Old Mine No. 4 and 50% Kentucky Dark Special Ball Clay

Table 16

CASTING BODY COMPOSITIONS

Schenectady Porcelain Plant

1
1925-1938

Tenn. (Jernigan) Ball Clay	23%
A-1 English China Clay	26
Canadian (Derry) Feldspar	31
Flint	20
	100%

Reason for Change: With ever increasing sizes of cast bushings a higher dry strength became necessary. Two stronger ball clays were added. Domestic china clays were substituted for English china clays, resulting in body change No. 2.

2
1939-1948

Bandy Ball Clay	20%
Old Mine No. 4	3
Dresden Ball Clay	3
Kamec Kaolin	12
Georgia Kaolin*	12
Canadian Feldspar	30
Flint	20
	100%

*No. 27 Georgia or Velva Cast Georgia China Clay

3
1949-1956

Body change No. 3 consisted of the substitution of Canadian Feldspar with 15% New Hampshire and 15% Virginia Feldspar.

Table 17

CASTING BODY COMPOSITIONS USED BY OTHER PLANTS

Westinghouse Co. Derry, Pa.

Kentucky Black Spec. Ball Clay	8%
No. 30 English China Clay	38
N.C. and Va. Feldspar	32
Flint	22
	100%

Ball clay and china clay ground in ball mill with water and electrolyte for 45 minutes. Feldspar and flint are then added and entire batch ground for another 35 minutes.

Hartford Faience Co.

Martin (Ky.) 5 Ball Clay	15%
Victoria (Tenn.) Ball Clay	8
S.C. Peerless China Clay	22
Me. & Conn. Feldspar*	36
Flint	19
	100%

Specific Gravity 1.80

Porcelain Products Co.

Bandy Black Ball Clay	13%
Old Mine 4 Ball Clay	7
No. 30 English China Clay	27
S.D. Keystone Feldspar	32
Flint	21
	100%

These bodies were tested at Schenectady for casting various types of smaller insulators, particularly cut-out boxes. The bodies did cast faster than Baltimore or Schenectady slips, but such fast casting bodies were also found to be "short" and a slight delay on the casting operator's part to open the molds resulted in cracked pieces.

Westinghouse obtained strength and density by applying pressure to the slip; without this the "W" body would be very impractical for casting large insulator shapes.

Note: Viscometer at Westinghouse, etc., is open top type, 7/32" orifice.
Specific Gravity 1.79-1.81, Viscosity 35 seconds/100cc slip.
Martin No. 5 ball clay and English china clay are used also by Lapp.

*These feldspars have a high free SiO_2 content and allowance has been made for this by using only 19% flint in the Hartford body.

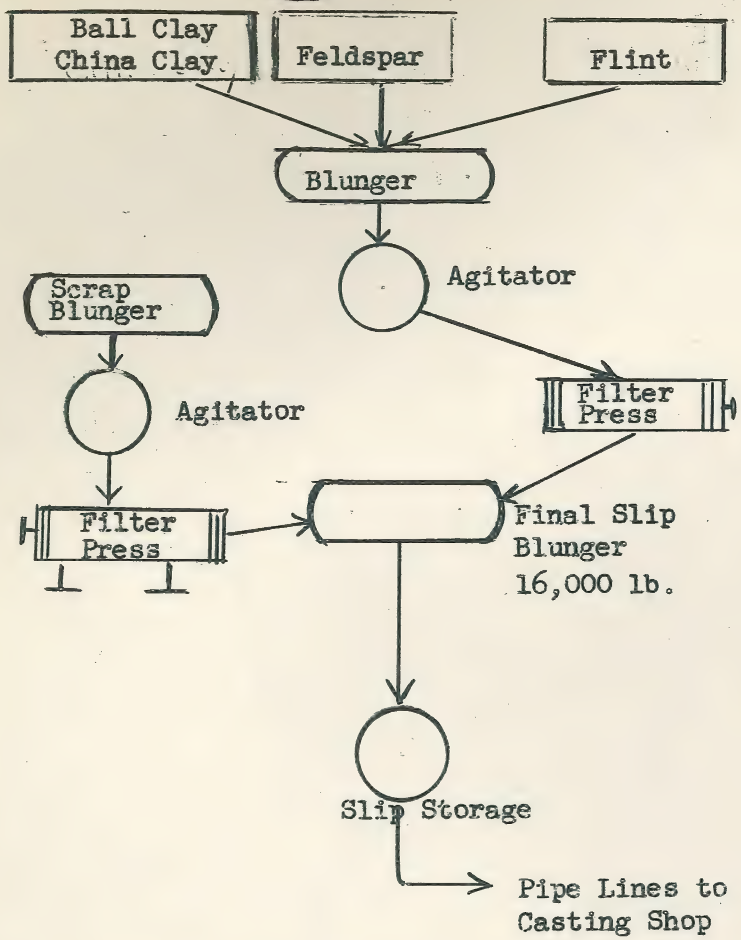


Figure 1.

Method of Slip Preparation at
Schenectady Porcelain Plant
Prior to 1936

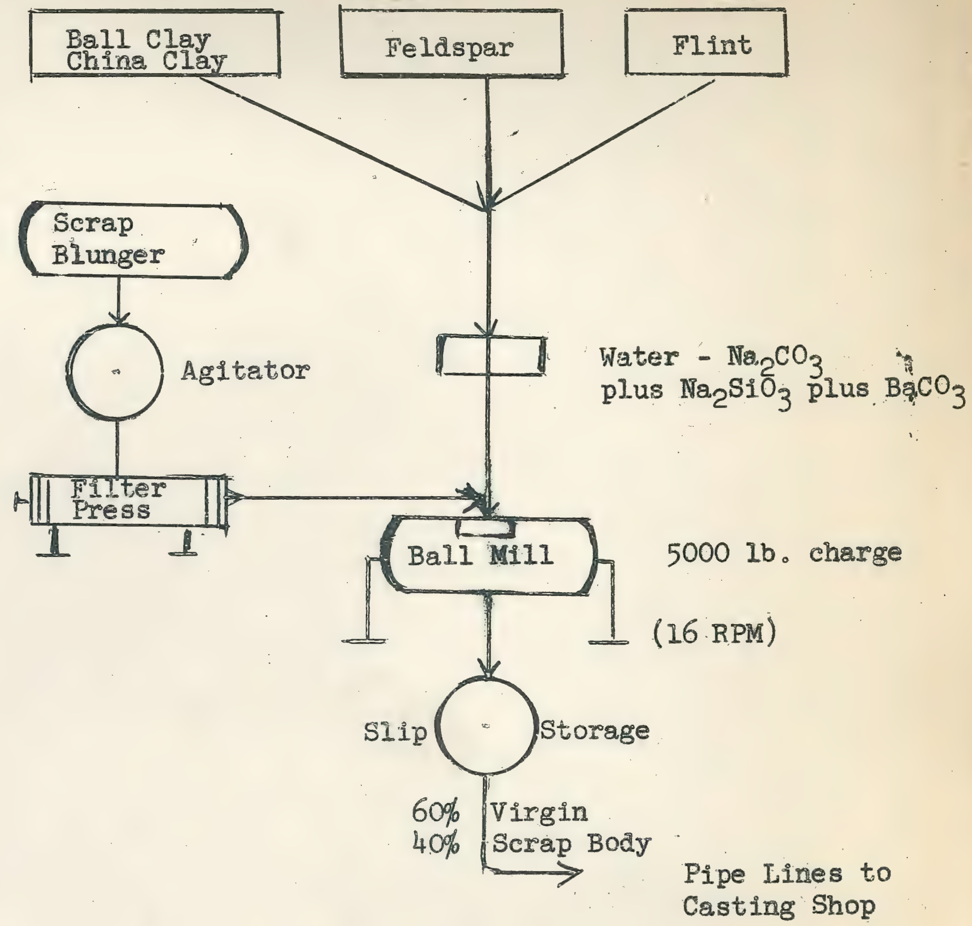


Figure 2.

Method of Slip Preparation at
Schenectady 1936-1941.

L.E. Thiess 1958

matter which act as deflocculant, colloid and stabilizer against gelling, are liberated and less soda is required to deflocculate the slip. Casting bodies low in ball clays (Westinghouse 8%, The Jeffrey DeWitt body with 7%) are or were prepared by ball milling in order to get the maximum benefit from the ball clay in the slip.

The third change in the method of casting body preparation was prompted by the ever increasing business in large cast porcelain bushings at Schenectady and Baltimore. The greater daily demands for casting slip made it necessary to abandon the lower capacity ball mill process (in 1942) at both plants. The casting slip is now prepared by what is known in the industry as the "direct method". In this simpler and faster method all the raw materials are loaded in a blunger and mixed with hot water and electrolyte into a casting slip with the specified specific gravity and viscosity, the latter obtained by final adjustment and control, if necessary through additional electrolyte additions. Improved slip screening equipment (Sweco) now eliminates undesirable lignite and other impurities from the slip.

"Direct (Blunging) Method" of Slip Preparation

This present Baltimore method of preparing the casting slip is presented in attached flow chart "Casting Body Preparation at Baltimore Plant". Reference is also made on this chart to manufacturing instructions and control methods which cover this process.

It is generally agreed that to obtain good casting results, the following most important, inter-related properties of the slip should be held constant: specific gravity, viscosity, i.e. flow, and rate of casting.

Factors of Slip Control

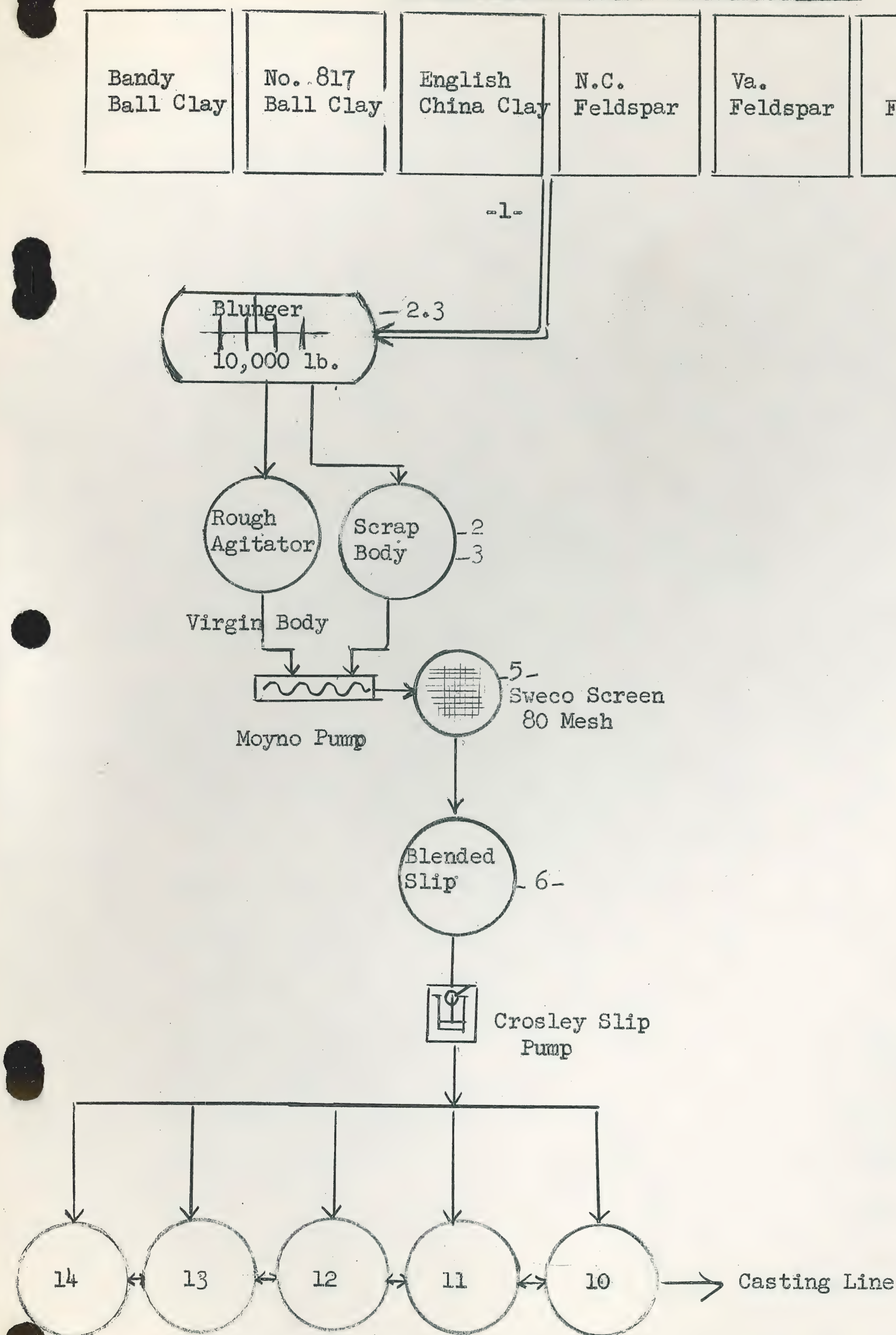
A short discussion of these follows:

a. Specific Gravity (Density)

The specific gravity is a good practical indicator of the water content of a slip. It is obtained through the simple expedient of weighing 100cc of the slip on a gram balance. A specific gravity of about 1.800 is used commercially, which means that the slip contains about 26.5% water. Best results are obtained with Baltimore slip weight of 1.810-1.815 grams/100cc.

Casting Body Preparation

At Baltimore Plant - "Direct Method"



Slip Storage -7-

Adjustment Agitators

Slip Control
(as marked)

1. Moisture Checks

2.) Electrolyte Additions
3.) Specific Gravity -
4.) Rough Check
MSN-B- 16

5. Screen Residue

6. Specific Gravity
Viscosity

7. Final Adjustment
Casting Trial at
Ceramic Laboratory.
Release for
Production.

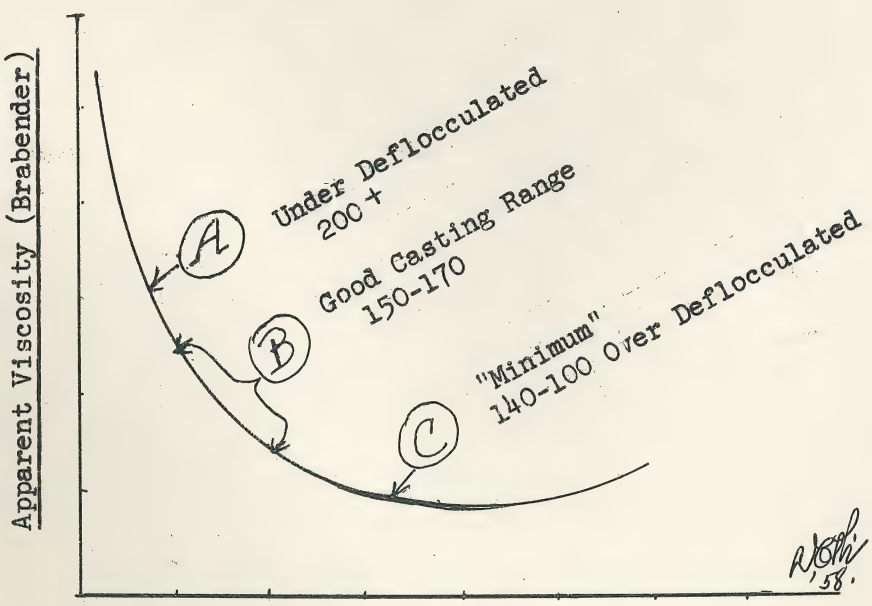
L.E.Th.
1958.

b. Viscosity

A property of equal importance is the viscosity, (resistance to flow); generally determined arbritarily by either measuring the number of seconds required 100cc of slip flow through the 5/32 - 7/32" orifice of an open cylinder, or by the use of a recording viscosimeter (Brabender, McMichael or Stormer type). Actually, alkaline casting slips have no "true viscosity", therefore, we might better speak of "apparent viscosity", or consistency.

Role of Electrolytes

Plastic body slip is usually made up with as much as 60% of water, whereas casting slips usually contain from 25 to 27% of water. This is due to the liquifying action of alkali salts which makes the slip fluid to a desired degree. This is illustrated in the following diagram, which shows a common viscosity - electrolyte curve in which the viscosity has been plotted against the percent of deflocculants added to the slip.



Percent Deflocculant
(Na_2CO_3 + Na_2SiO_3)

Most commercial casting slips are deflocculated to the left of that marked "minimum" (c) on this curve. A slip deflocculated beyond this point not only casts very slow, but tends to undergo segregation of the clay and non-plastics (feldspar and flint) in the slip. The formation of a dark brown scum on the slip is also an indication of an over-deflocculated slip.

The determination and control of viscosity by pH measurements have been tried on various commercial casting slips but have met with little or no success.

Effect of Water Hardness

The kind of water - soft or hard - has also a great influence on casting slip preparation. Due to the comparatively greater hardness (high lime content) in the Schenectady water, the amount of soda required for proper deflocculation of the casting body was about three times that as required with the much softer Baltimore water.

Effect of Soluble Salts

Soluble salts (calcium-magnesium-iron sulphates) in clays prevent easy deflocculation in casting slips. These salts may be precipitated and the amount of electrolytes reduced by the use of small amounts of barium compounds ($BaCO_3$ or BaOH) in the slip. Barium carbonate is the slower, the barium hydroxide the faster acting reagent.

If a casting slip becomes unduly thixotropic (i.e. shows temporary thickening or livering) an increase in the amount of soda ash will overcome this condition.

In tabulation (No. 18) is shown to what degree greater than permissible variations in specific gravity and viscosity affect the rate of casting as well as the quality of cast pieces.

C. Rate of Casting

Shape of Test Piece

While the rate of casting is somewhat more important with drain-cast than with core-cast pieces, in both cases it is important to know and control the wall thickness that is built up in the plaster of Paris mold for a given time.

The usual laboratory test piece consists of a cup which is filled with the slip and drained 10 minutes after setting. The wall thickness is measured on the leatherhard (in some cases dried) cup by cutting the same in sections. Sometimes the weight of the cast cup is also taken to supplement cast thickness.

Table 18

Effect on Casting Slip of Varying Water and Electrolyte Content

Experience has shown that variations in water content and electrolyte greatly affect success or failure in slip casting ceramic ware. The following list is prepared for comparative purposes, with one of the variables held constant. These effects may not necessarily be the same in the making of drain cast or core cast pieces, but quite often hold true in both.

1. With Specific Gravity Constant

High Viscosity Slip	Low Viscosity Slip (over deflocculated)
a. Fast cast - soft and spongy, slip retains a high percentage of water.	a. Cast fast at first, builds dense hard layer on mold wall, preventing further casting to desired thickness.
b. Slip thick, flows sluggish, drains poorly.	b. Thin, water slip - brown discoloration and scum, tendency to settling out of feldspar and flint (non-plastic materials).
c. Cast pieces of non-uniform density in cross section, cracking and warpage in fired large cast bushings.	

2. With Viscosity Constant

High Specific Gravity	Low Specific Gravity
a. Sluggish cast.	a. Thin slip, fast cast.
b. Gives greater strength at time of removal from mold.	b. Gives higher shrinkage, cast pieces crack in mold before core removal.
c. Pressure necessary to obtain solid cast - then low shrinkage obtained.	c. Lower strength in cast ware.

In view of the foregoing effect, it is of utmost importance to establish and then strictly maintain the specific gravity and viscosity values which, from laboratory tests and practical casting experience have shown the best results.

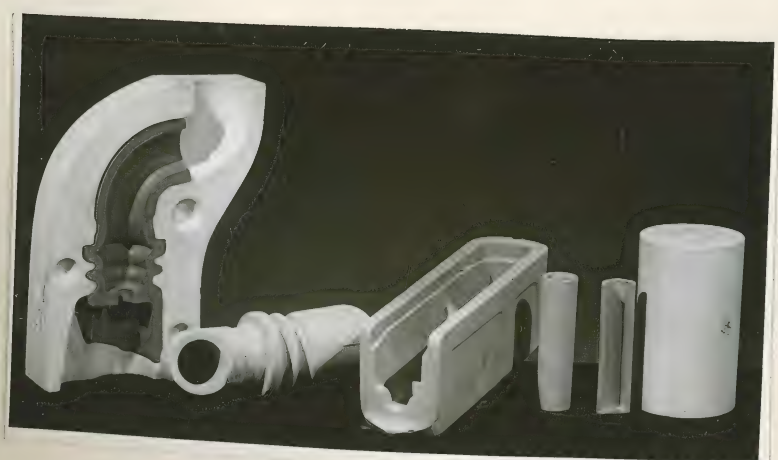
From the writers personal experience, the most practical test piece is to select a mold from a production unit, such as a goose-neck shape bushing for drain cast and a porcelain box for core-cast, or any other, but preferably one that presents some difficulties in making.

For many years, we have used, at Schenectady, test molds shown on attached photograph. The test molds were kept at a place near the production line, as atmospheric conditions, mold-drying equipment, etc., in the factory were somewhat different from that of an air-conditioned ceramic laboratory.

<u>Gases in Casting Slip</u>

Casting slip may undergo changes in aging. If aged for sometime, bacterial growth occurs and carbon dioxide (CO_2) and (or) methane (CH_4) gases are liberated from the composition of organic matter. Then gas bubbles remain entrapped in the cast insulators. A small amount of bacterial poison (formaldehyde) will help to prevent this trouble. Two to three quarts of this chemical have been added to 10,000 lb. of liquid slip.

Some other difficulties may occur in casting slips, for instance entrapped air, etc., and a discussion of the causes and remedies to prevent or overcome such difficulties will be discussed in the chapter on "Casting Methods".



Chapter VI. - Ceramic Forming Processes

Preceding chapters have dealt with G.E. Insulator Department and competitor's raw materials, body compositions, and the equipment and preparation of plastic and cast porcelain bodies.

In this present chapter the various ceramic molding processes will be discussed.

By comparison with older methods, which will also be described, the manufacture of modern electrical porcelain is fast becoming a highly mechanized, high production industry. Technical improvements have actually improved the quality and consistency of the product through constant engineering development of processes and methods.

On the other hand, the high laboratory requirement of many of these operations has, in recent years, brought greater emphasis of still using more mechanical methods of ware forming.

In most modern electrical porcelain factories there are essentially three lines of production flow:

Wet-Process

Wet Process Porcelain (Hot-Pressing
(Pug and Turn
(Ram Molding

Casting

Cast Porcelain (Core Cast
(Drain Cast
(Pressure Cast

Dry-Process

Dry-Process Porcelain (With and Without
(Applied Vacuum

The choice as to which of these manufacturing methods is used depends upon the size, intricacy, dimensional tolerance, electrical and mechanical requirements of the insulators, as well as the number to be produced.

In addition to the above three, some other, less common manufacturing methods, such as, for instance, isostatic pressing, etc., will also be discussed in this chapter.

Plastic Molding

a. The "Throwing" by Hand Operation

Throwing or

Jiggering Methods

Years ago practically all apparatus porcelains were made by "throwing" or "jiggering" on a turn table. The art of making ceramic ware by this method dates back to ancient times.

Briefly, "throwing" consists of the application of a pug of clay to a removable, circular plate. By hand, the plastic clay is worked up and down to equalize and shape the piece to the desired diameter and height. A central wooden paddle or pin is then inserted to form the hole, either only partly or all the way through. Smaller pieces are made by a single operator, but for large insulator blanks the help of two or three operators, as shown in photograph No. 1, is required. Then, the piece is set aside to dry to leather-hard consistency, after which the piece is turned on the lathe (photograph No. 2) or on another jigger to final shape.

The making of insulators by this hand operation requires highly skilled operators. At the present time only one operator is left at the Insulator Department to do such work. Since labor cost is very high, very few items are now made on the pottery wheel. However, the Lapp Insulator Company still makes a variety of insulators, for instance some of the larger station posts are made by this method.

b. Jiggering Porcelain Bushings

By another plastic forming method, widely employed in former years at the Schenectady plant, insulator blanks, especially those having a blind hole, were made in plaster molds on a "pull-down jigger", as shown in photograph No. 3. Here, an operator presses the plastic body into the mold and then forms the inside with a wooden pin or template.

Much larger pieces, up to 4' high and about 18" diameter were made also by the same method on a heavier pull-down jigger. A large chunk of clay from the pugmill was first spun up. Then the plaster mold was placed over it and then inverted and placed on the jiggering machine. The hole in the blank was formed by gradually moving a brass template into the clay to remove the excess, followed up with a solid wooden pin to give the final shape of the hole.

No. 1

"Throwing" Operation on Jigger

Radio Tower Insulator

No. 2

Turning on Lathe -"Leather Hard"State

Radio Tower Insulator

At Left: Turned piece and fired piece. Baltimore Plant

No. 4

Pull Down Jigger - Making Blanks in Plaster Molds

Closed Top Bushings, Schenectady Plant

No. 5

Pressing Large Blanks in Plaster Molds at Ohio Brass Company

-To Page 49-

In a somewhat similar manner very large porcelain bushing blanks are molded in plaster molds at the Ohio Brass Insulator Plant at Barberton. The lower picture on attached photo No. 4 shows an operator forming the hole in the plastic clay. Recently, this clay from a vertical pug mill is directly extruded into the mold, which is then transferred to the pull-down jigger. This process is quite costly and slow and requires highly skilled operators, but it has the advantage that such large blanks can be made with either straight or taper holes. In other plants bushings with taper holes can only now be made by jiggering and slip-joining or casting and glaze-joining individual sections.

C. <u>Hot Pressing (Plunging) Method</u>

For more than 40 years all porcelain insulators of circular-contoured design (suspension type, fog-type, and pin-type) have been made by the hot-plunging method. Only in recent years has it become a modern, production-line method in the partial or total elimination of hand operations.

<u>Hot Press Method</u>

Except in England, where high ball clay bodies, similar to American are used, no other European continental insulator plant employs the hot-plunging method. The German high voltage porcelain bodies are not plastic enough for this work.

<u>Ball Making -</u>

<u>Old and New</u>

The customary procedure is as follows: A measured pugged column is made by frolling or patting into a cone shaped blank called "ball" and the operation is called "ball making". It has been and in some quarters it is still the belief that this manual ball making is an essential operation and tends to work out non-uniform structure and stresses introduced in pugmill extruded blanks. The recently constructed automatic "ball making", i.e. hot pressing of a cone-shaped ball, which eliminates the above hand operation at Baltimore, has greatly discredited the older ball making method. As a matter of fact, more often flaws, folds, etc., have been in the past introduced by a careless ball maker, resulting in head cracks, distortion and other defects in the insulators. With the new method, suspension insulators are now made with more consistent M&E values and practically no variations in puncture strength. The new Baltimore method is shown in attached photograph No. 5.

New "Ball" Forming

and

Tamping Operation

Figure 5

Vacuum pugmill extrudes two blanks at same time. These are automatically cut to required length (electric eye). Two "balls" are formed by hot-pressing, placed in plaster molds on the tamper (index table) for pre-forming. The next operation is the actual pressing by the hot plunger.

To Page 50

The actual hot plunging is done on press with a revolving, steel die called a "plunger". In most cases it travels on a vertical axis and the plaster mold is stationary while on some other presses the reverse is the case. Heat is applied to the plunger by a gas flame so that the hot tool, in contact with the clay, provides a layer of steam for quick release. A small amount of a special oil is spread by hand over the clay surface. With the proper heat and clay stiffness a smooth, blemish-free insulator shape is obtained. The attached photograph No. 6 shows the hot plunger just leaving the pressed piece while the press operator removes the flash with a flat tool.

Hot Pressing

The temperature of the plunger die is very important. A cold die causes the clay to stick and twist, producing pinhole cracks. An over-heated die, on the other hand, produces a burned and pitted surface which can only be removed by an excessive amount of trimming and sponging.

It is reported that the Illinois Porcelain Company now employs an automatic gas heated plunger with a temperature control between 250° and 275°F. Test runs with an experimental temperature control equipment indicated that a plunger temperature between 230°F and 250°F gave good results. No permanent installation of this equipment has, at this writing, been made here at the Baltimore plant.

Plunger Temperature Important

Electrically heated dies were employed several years ago at the Schenectady Plant. The heat recovery, however, was slow. Perhaps some electric units with faster heating rate and control will be developed that can be built into the dies to replace present gas heated plungers. An electrically heated die for 10 inch diameter suspension insulators is shown in a recently published new Japanese insulator catalog (Nippon, Gaishi Kaisha).

At Baltimore, and in most other plants, the former "solid type" steel plunger dies have been replaced with "spaghetti" dies. The former consists of several solid rings with a narrow air space between and the rings supported in the back by a spider. The "spaghetti" die is of a less expensive design. It has a great number of 1/16-1/8" diameter holes to release the air and at the same time allows surplus clay to squirt out in form of spaghetti shaped sections. Spaghetti blungers leave an even, smooth finish on the pressed piece, requiring a minimum trimming and sponging.

Plunger Design

In comparing the methods employed in the manufacture of suspension insulators at the G.E. Baltimore plant with those at competitors plants, some interesting variations can be found, which, in the writer's opinion, warrants a brief discussion.

(1) Some plants still use the old method of ball making. In placing the ball in the mold, the operator hits the clay with a bat-out mallet to seat the ball in the mold. Both operations call for a high degree of skill and are entrusted only to specially trained men. More recently at Baltimore and some other plants [1],[2] pre-pressing equipment and automatically operated tampers are employed which have eliminated the hazards associated with hand operations.

Tamping Clay

(2) In some insulator plants the plastic clay in the mold is subjected to rapid vibrations of low amplitude during the preforming or final hot plunging operation[3],[4]. Some of these methods of vibrating the clay were employed as far back as 30 years ago and appear to have been of

1. Ohio Brass Company
2. Lapp Insulator Company
3. Pinco Insulator Company
4. Westinghouse Derry Plant

advantage at the time of the old vertical pugmills that operated without de-airing equipment. The clay received from these pugmills was usually not of uniform density and was more or less laminated or stratified. As far as the writer can find, the only place where clay blanks are vibrated in molds today (against a solid stationary plunger) is at the Pinco Insulator plant. The general idea of tamping or applying vibration, of course, is to solidly pack the plastic clay into the mold cavity, thereby to eliminate the uneven density that usually exists between the head and skirt sections in suspension and other insulators made by the hot-pressing method.

Vibrating Clay

With the hot plunging completed the mold containing the pieces are placed for conditioning to a leather-hard state by fans on an overhead conveyor (G.E. Baltimore), or through an infra-red lamp mold release dryer (Victor and Illinois). At Porcelain Products Co., Parkersburg, W. Va., a gas-heated mold release dryer is operated through which the charged molds travel in one direction, the insulators are taken out and the empty mold dried by circulating hot air, returning in opposite direction back to the press.

Mold Release

In the next operation the insulators are finished (trimmed and sponged) according to blueprint specifications and then placed on trucks to go for final drying (at Baltimore down to 5-6% moisture) in humidity controlled dryers, later to be glazed, sanded and fired.

Finishing Operation

Clay Shrinkage in Porcelain Insulator Manufacture

In the preceding pages the hot molding of suspension insulators from soft, plastic clay by a spinning tool, called a plunger, has been described. This is done while the clay is in a water absorbing mold which supports the clay until partially dry and capable of handling. During this process the clay shrinks away from the mold, thus freeing it.

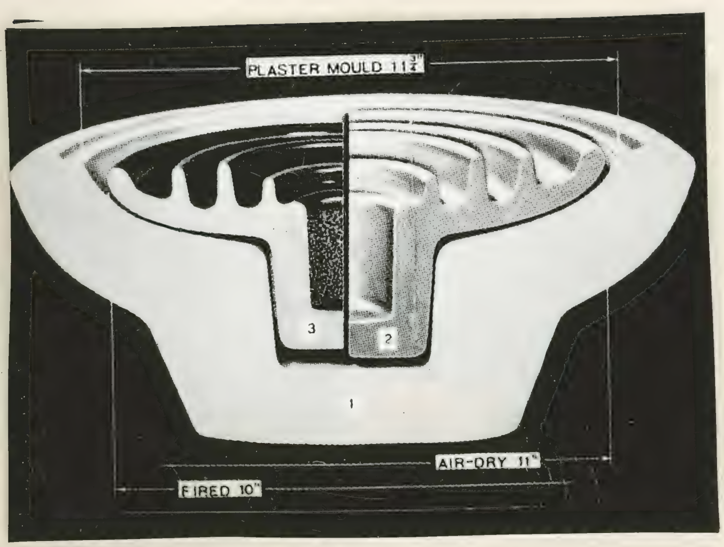
Drying Firing Shrinkage

Shrinkage in porcelain as well as in all clay materials is a complex phenomenon. In going from the wet to the dry state, the change is not symmetrical - the clay shrinks more in some direction than in others. Orientation of the body grains (plastic as well as non-plastic) takes place during pugging and molding and all these operations leave a "history" or memory in the plastic body which shows up through the later stages up through the end product.

A good example is shown in attached photograph, showing a cross section of a plaster mold, dry suspension discs and the finished fired piece.

The 1840A suspension insulator starts with a hot pressed shape (in the mold) having a diameter of 11-9/16 inch to produce a fired insulator of 10 inch diameter. This is a reduction in size of 15 percent, which must be taken into consideration in the making of molds and tools.

1. Plaster Mold
2. Air Dried Insulator
3. Fired Insulator



Jiggering Switch Shells

This method of shaping insulators is done on a modern version of the age-old potter's wheel. It requires a high degree of skill and experience.

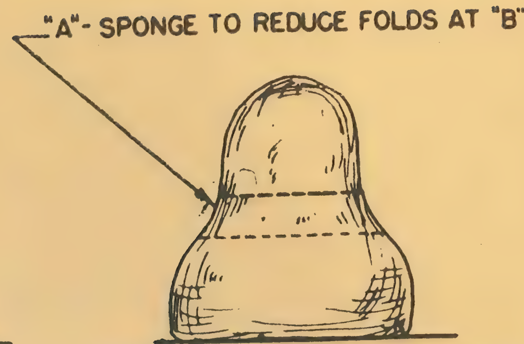
The operation consists of making first a pug of plastic clay into a hand-rolled, conical shape which fits into the head recess of the mold. The clay is then pounded and spread around the mold with a cloth-lined wooden mallet. With his fingers and a wet sponge, the operator makes a center-hole and widens the same enough so that he can gradually insert the jigger tool or profile into the rotating clay. The usual six (6) stemps of this jiggering operation are illustrated in the attached series of sketches. The attached photo also shows an operator jiggering one of the switch insulator shells.

Jiggering Switch Shells

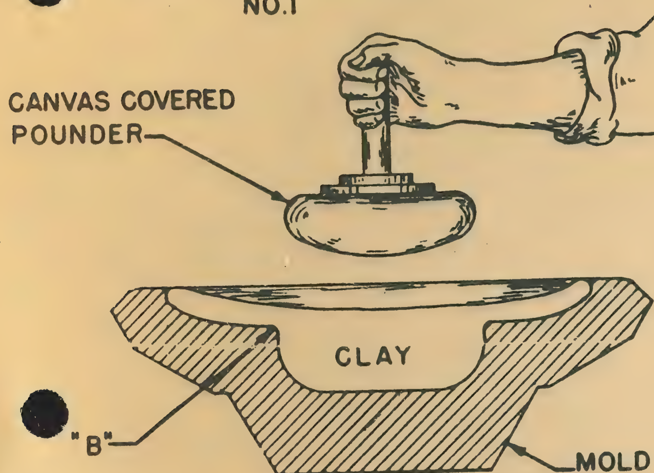
The jiggering method is employed primarily for larger or special shapes that cannot easily be made by the hot-plunging. At Baltimore, the largest piece made is a switch insulator shell (No. 79604) having an outside diameter of 20-5/16 inches (wet shape).

CLAY BLANK FROM PUG
NO.1

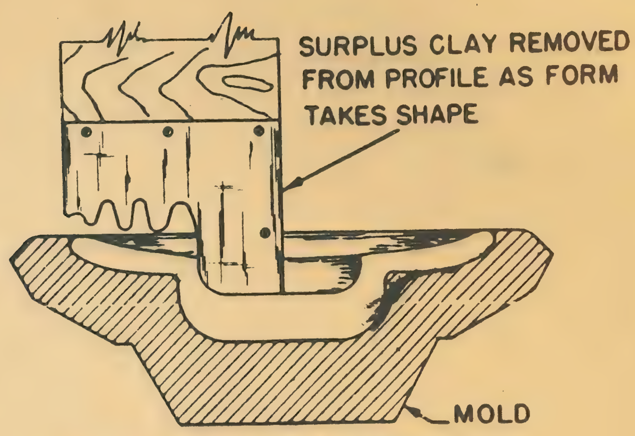
SHAPE
NO.2



FORMED BALL READY FOR MOLD
NO.3

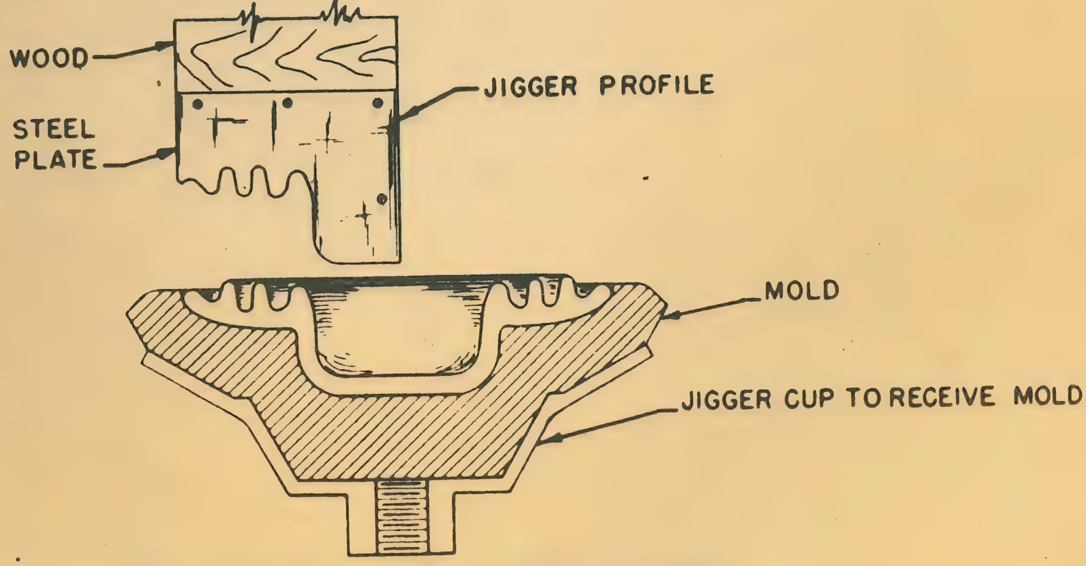


CLAY BALL POUNDED TO POSITION
READY FOR JIGGER
NO.4



SHOWING PROFILE ENTERING CLAY

NO.5



PIECE FINISHED SHOWING PROFILE LIFTED
NO.6

Green Finishing

The mold containing the jiggered pieces is usually stacked on the floor in the jigger area. Hours later, when the clay has stiffened and shrunk away from the plaster mold, the pieces are removed for the finishing operation, known as "Green Finish", i.e. in leather-hard state.

Suspension insulators and switch insulator shells are normally finished by hand. The insulator is placed on a rotating head or hump where the flash or fettle is removed with wire cutter. The final finish is made with a wet sponge, followed by a rubber pallet.

Machine finishing is done similarly except that a profile knife, accurately shaped to contour, is pressed against the rotating insulator body, removing enough of the clay to meet the desired dimensions. These, of course, must take into account the shrinkage which will take place during drying and firing.

After this green finishing the insulators go into a humidity controlled tunnel dryer where the remaining water content is safely reduced down to 5-6%. The dried insulators are then inspected and a band of semi-conducting glaze applied. Then, the insulator is glazed and sanded and ready for kiln firing.

Jiggering

vs.

Hot Pressing

Due to the high labor cost and requirement for skilled operators, we at Baltimore have several times in past years tried to make these large swtich shells by conventional hot-pressing operations, i.e. hand rolled ball - hand tamper and hot pressing. An example of this is porcelain shell Dwg. 79047 which has an outside diameter of 19-1/2". The insulators were made on the 24" hydraulic plunging machine. As far as we know, Westinghouse (Derry Plant) as the only other insulator plant has, for years made such switch shells by the same hot-pressing method.

While the manufacturing cost for hot-pressing such switch shells is approximately 20% lower than for hand-jiggering, it was also found that the mold breakage on the hot press was very much higher. The electric puncture losses were also higher than for jiggered pieces, which is due to folds being introduced into the insulator during hot-pressing of the pieces. At the time of writing this, all these large diameter shells are now made by jiggering.

However, quite recently new efforts have been made here at Baltimore to adapt the previously described new three-step (hot-pressed ball - hydraulic preforming tamper) and hot plunger method employed in making the 10 inch suspension insulators as shown in photograph page 50) to make these large diameter switch shells by this same process. If successful, appreciably lower manufacturing costs will be the results.

Ram Plastic Molding

RAM PROCESS

Another, more recently developed, method of molding high voltage insulators from plastic bodies is known as the Ram Process. This process is particularly adaptable to fuse boxes, bus supports and similar parts. The R. Thomas & Sons Company at Lisbon has been making 6" suspension insulators. Large scale production of cut-out boxes has been in operation at the Hartford Faience Company and at the Illinois Porcelain Company.

Ram pressing for the plastic forming of clay uses high strength but porous plaster dies reinforced with steel and imbedded air ducts, as shown in the following photograph No. 1.

Photo. #1. Ram Working Mold and Rubber Master Mold (left)

A complete mold assembly for a porcelain cut-out box, mounted on the hydraulic press is shown in photograph No. 2.

Photograph No. 2. Top and Bottom Mold and Plaster Pressed Cut-out Box.

As the plastic clay slug is pressed into shape, the water is forced out into the porous plaster. Just at the moment of complete closing, air enters the plaster of the lower plaster die and "pushes" the formed clay away from the die. As the upper rises, the pressed piece goes up with it. Then air is applied through the plaster of the upper die, thus releasing the piece from the cavity.

By this Ram method an operator can produce from 600-650 cut-out boxes per day which represents a considerably lower cost than by casting these porcelains in plaster molds.

Photograph No. 3 shows the lower plaster mold for pressing two bus bar insulators at one time.

Photograph No. 3.

Ram Pressed Cutout Boxes and Bus Bar Insulators

The successful operation of making such pieces as cut-out boxes depends upon the following critical factors:

a. Uniformily conditioned plastic clay of proper stiffness (27-30), moisture 18.3-19.0%.

b. Pugged blanks of special shape for each item to be pressed.

c. Proper placing of blank on the mold to allow uniform plastic flow of clay during pressing and prevent folds in the pressed piece.

Ram Pressed Suspension Insulators

In 1954 we conducted some experiments at the Ram Co., Columbus, Ohio, to press 6" diameter suspension insulators. The results were not successful. No only were the crack losses very high, but 8 out of 10 fired and assembled insulators failed to meet the required M & E test specifications.

It has also been reported that R. Thomas Sons abandoned the making of suspension insulators by this Ram process. Apparently no other insulator plant is presently making this type of insulator by this method. Perhaps, more experimental work must be done to show whether such suspension insulators can successfully be made by the Ram Process.

Compared to casting, the Ram molding of cut-out boxes shows a considerable labor cost reduction, which is about 30-35%. Adding to this the elimination of required large amounts of (plaster) casting molds, which must be replaced after 80-85 castings, the economical advantage of the Ram process over the cast process becomes very evident.

Slip Casting

Cast Porcelain

Large porcelain bushings, especially those of conical shape and other insulators of complicated and unusual design are made by slip casting in porous plaster of Paris molds.

This method consists of pouring a liquid porcelain slip into molds which absorb a sufficient amount of water from the slip to make the piece rigid enough to be removed from the molds.

The method of forming insulator shapes by casting is usually quite high in cost; it requires not only the making of patterns or master molds, but also an upkeep of a large number of production molds. These plaster molds are with repeated use of 50-80 times (depending upon the dimensional requirements of the cast piece) subject to mechanical and chemical deterioration and must then be replaced at substantial costs.

Despite these facts this method of manufacturing is, nevertheless, widely used in the industry. This is because of the uniformly high quality porcelain obtainable and the ease with which the method lends itself to the manufacture of unusual shapes and sizes.

The casting of large sectional bushings for transformers and circuit breakers was pioneered many years ago at the Schenectady Porcelain Plant.

Westinghouse (at Derry) and the Canadian Porcelain Company (Hamilton) are the only other two insulator plants engaged in casting such large porcelains. Smaller pieces are cast at Hartford, Illinois Porcelain and at the Lapp plant.

The large variety of plaster molds and cast porcelains is shown in attached photo No. 1, showing a section of the Baltimore Casting Shop.

The raw material requirements, i.e. the ball clays and china clays found most suitable for use in casting bodies, have already been discussed in Chapter V.

Generally speaking, the casting operation is analogous to filterpressing, i.e. a de-watering process. Since with the water absorption from the slip by the porous plaster molds progressive shrinkage occurs, it is necessary to produce a slip of high specific gravity and one which forms a casting permitting free passage of water.

There are several methods that can be employed in casting electrical porcelain, each depending upon the size and shape of the piece. But, in general, these methods consist either in drain casting or solid (core) casting.

Various Methods Employed

Considerable experience is necessary in the designing and in making the necessary master and working molds.

a. Drain Casting

This method consists of pouring the liquid slip in plaster molds. After the desired wall thickness is set up, usually 1/4 to 1/2 inch, the remainder of the slip is drained either by pulling the plug from the bottom or simply by turning the mold over.

Drain Cast

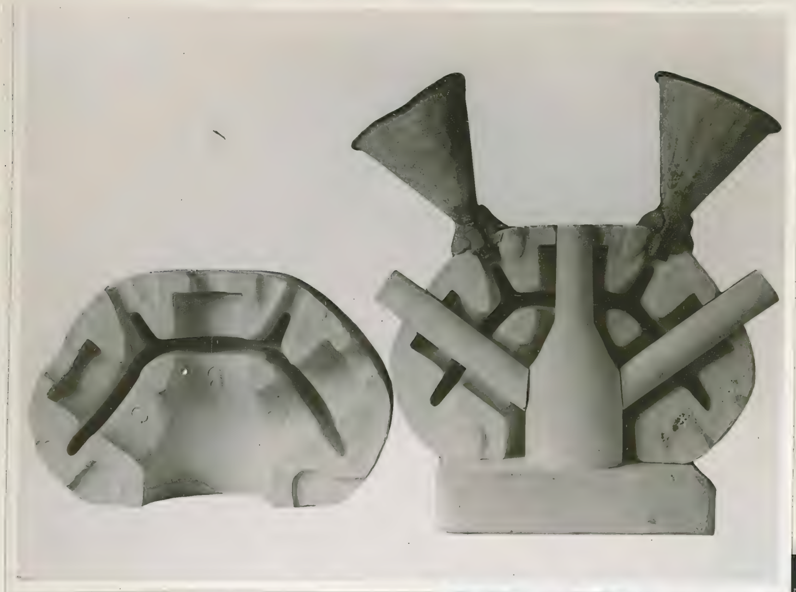
An example of the former is shown in the cast curved bushing shown in the photo on page 47.

The actual casting time is about 35 minutes. An hour later the cast piece has become rigid enough to be taken out of the mold. It is then trimmed, steel wooled and glazed.

b. Solid Core Casting

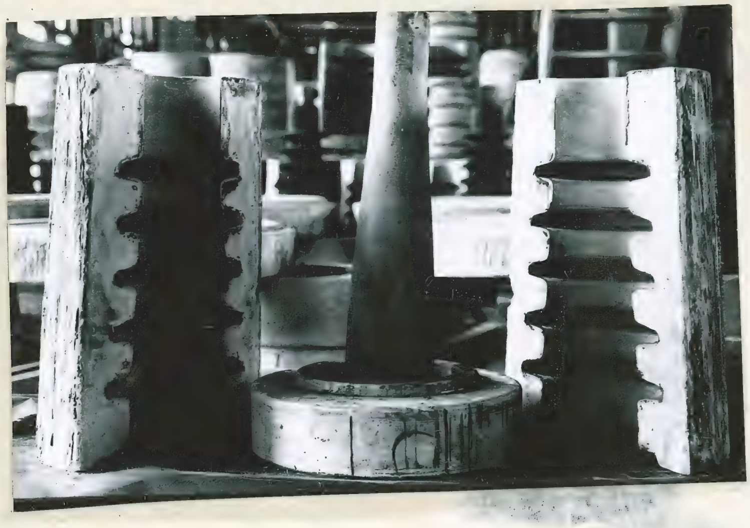
Solid (Core) Cast

Solid or core casting is mostly widely used in the production of very thick or large shapes with walls up to 4 inches thick. Others, more complicated pieces, as for instance the bushing shell (No. 2525776) are cast in molds consisting of six parts, photograph No. 2.



Another example of core casting is presented in photo No. 2. The mold here consists of two side parts, one core (not shown) and a top plate with two holes holding the funnels. The cast insulator has a closed end, somewhat similar to Locke station post insulators.

The plaster mold shown in photograph No. 4 represents one of the many used for casting single or multiple part porcelain bushings.



Practically all casting jobs, large and small, must be done according to a definite time schedule. The actual casting time for bushings cast in the above mold is from 14-16 hours. The molds are usually filled late in the afternoon, using an approximately 2 ft. high header for additional slip supply during the night. This feed is cut off early the next morning. Two hours later the side parts are removed. The cast bushing, with the core left inside, is left upright on the bottom support ring. Two hours later the cast piece is lifted from the core and placed aside for air drying.

The height of the liquid head above the actual casting mold is very important. Usually a plaster ring 4-8", or metal funnels, as shown in photograph No. 5 are used to obtain a sufficient head to make a solid cast.

Pressure Casting

As early as 1927 experiments were made at the Schenectady plant by applying air pressure to the slip in plaster molds to accelerate the casting and shorten the manufacturing cycle.

Pressure Casting

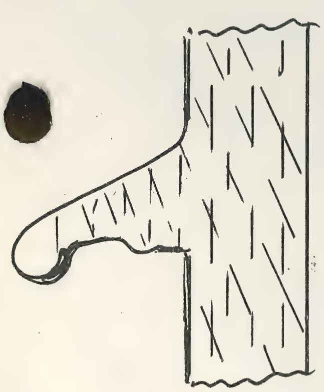
No. 5 - Metal Cylinders of Various Heights Above
Plaster Molds Insure Solid Cast Pieces

-To Page 64-

Later, in 1938, a number of one piece transformer bushings were pressure cast at Schenectady on regular production schedule, using 20 lb. psi air pressure. This writer saw cut-out boxes cast at the Lapp plant with 5 lb. psi air pressure applied to the slip.

The Westinghouse (and formerly the Canadian Porcelain Co.) are the only plants where this method of casting large, single piece transformer bushings, up to 24 inch diameter and up to 9 ft. high is now employed. At the Westinghouse plant, 15 lbs. psi air pressure is used. The wall thickness also depends upon the plasticity (grain size) of the slip, the nature and amount of ball clay in the body and the time of the slip held under pressure.

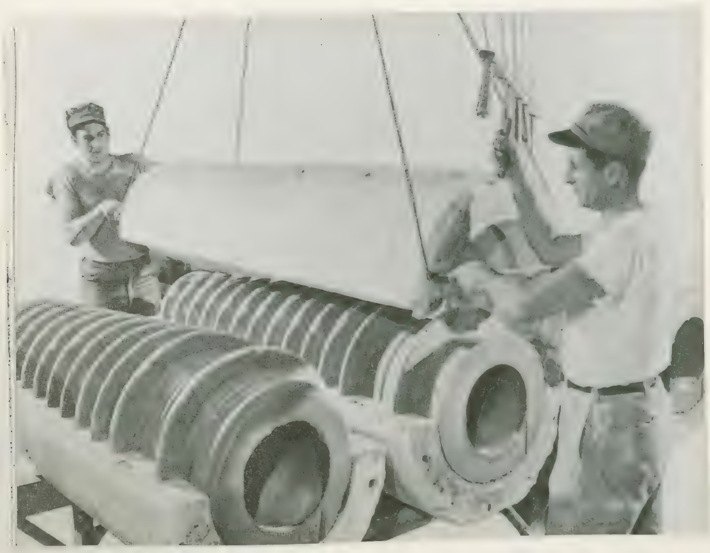
As shown in photograph No. 6 the heavy banded, with steel rods, assembled plaster molds are filled with slip under pressure from the bottom. This eliminates entrapment of air bubbles in the cast piece. When completely filled, air pressure of 15 lbs. psi is applied at the top. The largest pieces cast up to the desired wall thickness (1-1/2 inch) in 5 hours. Then the slip is drained from the mold and a slight air pressure, approximately 2 lbs. psi is applied to dry the wet slip inside the cast piece and prevent collapsing in the mold. The cast pieces are left in the mold for six to twelve hours. Then the mold is turned into horizontal position, the half shell removed and the piece turned over into a drying mold (called cradle) where, in a course of hours or several days, the piece is hard enough to be removed for trimming and sponging prior to glazing and firing. The inside of these pressure-drain cast bushings is uneven, as it follows the curvage of the outside bushings. However, in other respects the structure of pressure cast porcelain is generally more homogeneous, uniform, and free from the stratification or even segregation that to a smaller or larger extent often occur in core cast porcelain.



Core Cast

Pressure & Drain Cast

Photo No. 6 - Mold is Filled with Slip From Bottom. Operator (on top) Adjusting Steel Plate With Slip Reservoir.



Molds Being Opened to Transfer Cast Piece to Drying Mold.

-To Page 65-

This pressure casting of large, single piece porcelain bushings is a comparatively slow and expensive method. The casting molds must be of extra heavy construction. They require a perfect fit and extra supporting shells must be provided to dry the pieces in horizontal position. Such large bushings cannot be turned on the lathe, they are also subject to greater distortion in drying and firing. A great hazard is to transport and load these large single piece bushings in the kilns. A special hand operated hoist, mounted on a truck is used. Gripping and hoisting such heavy unfired pieces so that they can be lifted without damage is accomplished by the use of an inflated air-tight nylon covered rubber bag. Another drawback is the large floor space required to do this work.

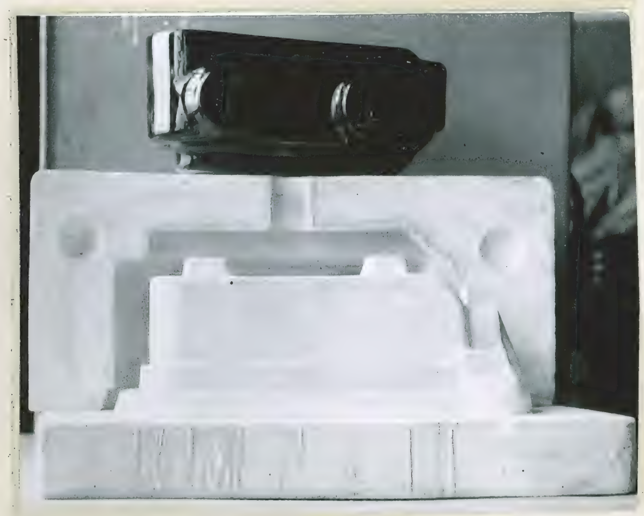
While this Westinghouse method of making large one piece bushings undoubtedly has some interesting features, the high labor costs and the high manufacturing losses involved have prevented its adoption both at the G. E. Schenectady and Baltimore, as well as other competitor plants.

Three other methods of casting insulators have been used, sometimes on production or experimental scale, which will be briefly described.

Over Cast Method

Over Cast

Insulators to be made by the cast process should be designed with a uniform cross section. However, ocassionally an article is required, like the J.D. (Line Material) cut-out box, which bottom section is much heavier than the side walls.



J. D. (Line Material)
Cut-out Box

Such pieces cannot be cast successfully in one piece and the only practical solution consisted of casting the thick bottom slab in a separate mold. Then, when this piece is just rigid enough to be handled, it is placed immediately into the actual cut-out box mold and the slip is cast over this inserted bottom section. This "over-cast" technique is extensively employed in the Sanitary Porcelain Industry. The joining of these separately cast sections can also be improved by coating the surface with casting slip to which a small amount of table salt (NACl) has been added.

Vacuum Casting

Vacuum (Suction) Casting

A vacuum has occasionally been applied to the core or other section of a plaster mold to suck the excess water absorbed from the slip. This finds a practical application where the core is of small cross-section and becomes quickly saturated and thus ceased to draw any more water from the slip.

Centrifugal Casting

Centrifugal Casting

The centrifugal casting of ceramic ware has only been successful with body slips consisting essentially of only one or two materials of very uniform grain size (Titanate or high Alumina bodies) and high specific gravity. Such castings have been made by revolving the plaster mold at 1000 rpm for a period of 30-45 minutes.

Regular porcelain slips which are a heterogenous mixture of ultra-fine clay and comparatively coarser feldspar and flint particles will show considerable segregation after centrifugal casting. The finer particles were found to have been carried out to the face of the mold with a gradual increase of particle size from the surface to the center of the piece. This lack of homogeneity results in unequal shrinkage and density in the fired porcelain.

In concluding this chapter on the forming of insulators by casting method, it is pointed out that many factors contribute to either success or failure in this work.

Plaster molds, for instance, their proper design, density, and maintenance have a great effect on the quality of cast pieces. The abundance of technical literature covering the subject of casting slip making and control is also an acknowledgement of its importance.

Some of the defects in cast insulators and their causes and cures will be discussed in a later chapter on "Manufacturing Difficulties and Manufacturing Losses".

Chapter VII - Pug and Turn Methods

With the exception of a few special insulator shapes for which there are usually only small orders, practically all apparatus porcelains are made by pug-and-turn methods. By these methods cylinderical, rectangular or oval blanks, either solid or hollow, are first extruded on an auger machine, known as a pugmill, and these blanks are then in a leatherhard, or bone dry state, turned into the desired insulator shapes.

Long before porcelain insulators were known, the brick and tile manufacturers made products by extrusion on auger machines. These pugmills were almost all of the horizontal type.

Pug Mill Designs

And

Extrusion Methods

The pug mills used in the electrical porcelain industry to about twenty years ago were vertical machines. They were made either by the Crossley Company (Trenton) or Patterson Company (East Liverpool). An example of such a pug mill, of which we had a number at the Schenectady and Baltimore plants, is shown in Photograph No. 1.

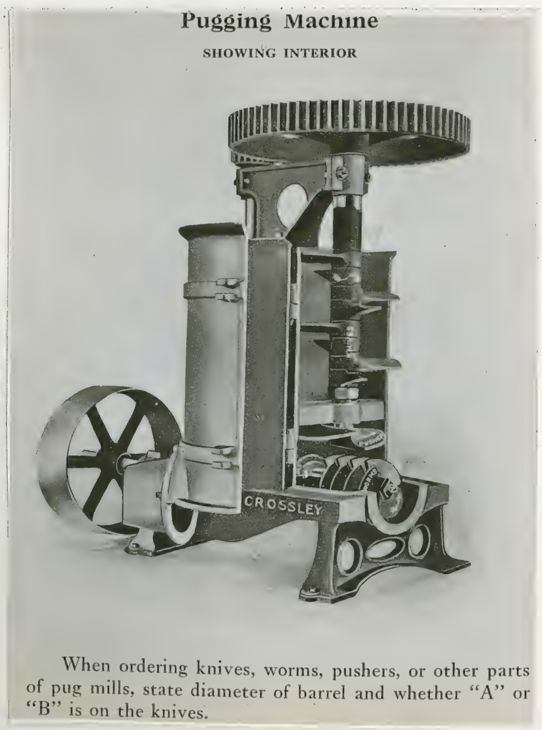


Photo. #1 Crossley Pug Mill

The results obtained on these machines were none too good. The extruded blanks were often found with auger laminations and entrapped air, resulting in drying and firing cracks and in electrical punctures.

De-Airing Pug Mills

A great improvement was made during the 1930's by the introduction of (horizontal) vacuum extrusion machines. These pugmills soon replaced all the older vertical machines. Electrical porcelain plants today have either Bonnot or Fate-Root-Heath vacuum pug mills, the latter are better designed and, therefore, preferred by the insulator industry. An example of such a vacuum pug mill and a set-up for extruding blanks up to 20" O.D. (extruded) is shown in Photograph 2.

No. 2 Bonnot V-62-B Vacuum Extrusion Machine

The operation of these pug mills are simply as follows. The pug mill knives in the hopper section feed the clay to a compression auger, which in turn feeds through a cone-shaped die to form the air seal. A high speed shredder cuts the clay into 1/8" thin slices, thus releasing the trapped air. A vacuum between 28-1/2 and 29 inches is maintained in the de-airing chamber. The shredded clay drops into the lower main auger chamber to be extruded through the nozzle and forming die.

Usually only one simple tapered die (6-7" in I.D. max.) is supplied with the pug mill. It is left to the insulator manufacturer entirely to design and attach any other barrels, rings and nozzles for the great variety and sizes of solid and hollow blanks to be made on such pug mills.

In spite of the various improvements in vacuum pug mills, auger laminations in solid blanks over 7" diameter is still a problem today.

One of the most common defects in such blanks is a "S" type crack such as shown on the left piece in Photograph No. 3.

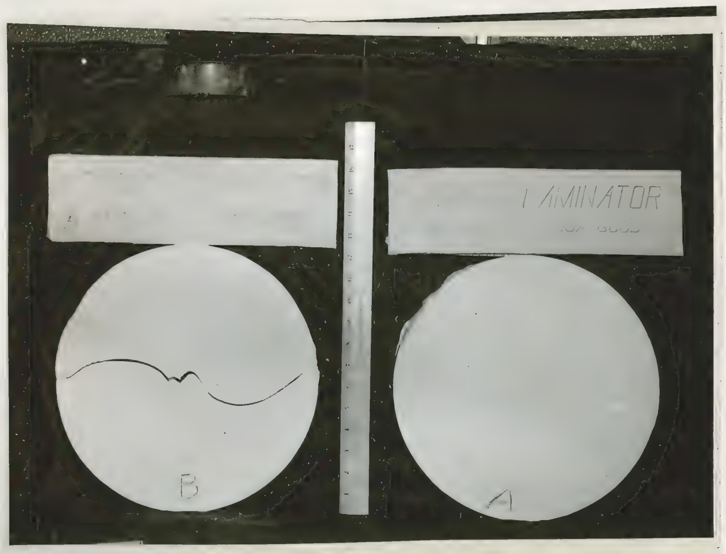


Photo. #3. Left Sample from Regular Pug Mill Blank. Right Special Mixing ("Delaminator") Attached to Pug Mill.

Barrel Design

For any particular plastic body, the structure of the extruded clay is the product of the effect of the auger and the effect of the barrel and die set-up beyond the auger. A great number of methods have been tried to improve the structure only to find that any method which changes one structure leaves another. The problem then to design and adopt a barrel design which minimize clay variation and to

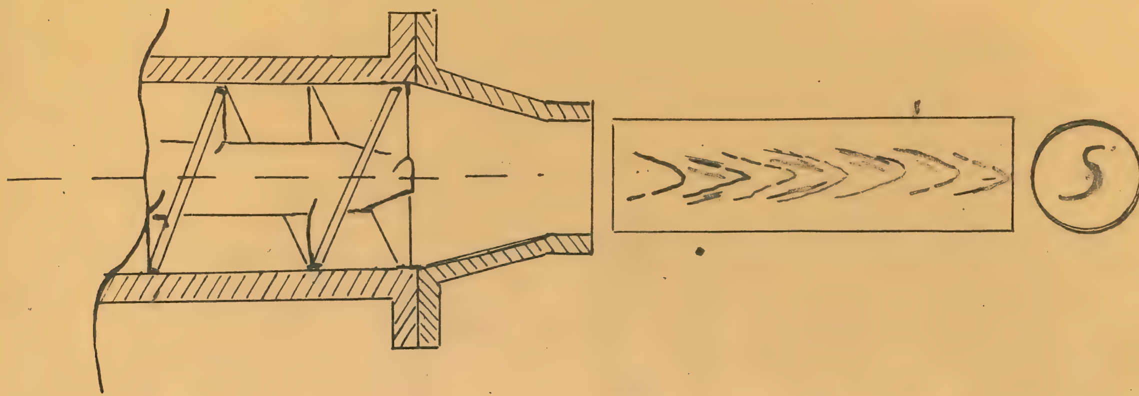


Figure 1. Poor die set-up. With such short nozzle, blanks with internal weakness are produced.

Figure 2. Additional, large diameter barrels and double extrusion die produce solid blanks.

Example: Auger barrel 8" diameter. Three additional barrel sections 16" diameter - total length 46". Extrusion die consists of 1" plate, extruding two blanks 5" diameter each, for 10" suspension insulators. Results satisfactory. No "S" cracks, uniform density.

INSULATOR

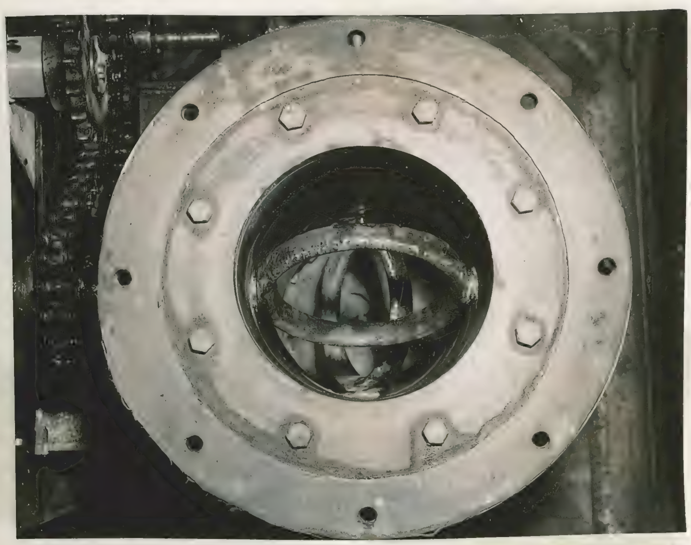
LOCKE DEPARTMENT GENERAL ELECTRIC COMPANY BALTIMORE, MARYLAND DWG. DATE		U- L.E. Thiess 9/1958

obtain a reasonable uniform flow across the face of the die. Some of these barrel designs are shown on attached prints, with Figure 2 and 3 the now commonly adopted by the insulator industry.

Other methods have been tried, consisting of placing stationary cross-bars, spiders, screen, slotted plates or venturi-shape restrictions in the pug mill barrels ahead of the nozzle to re-mix the clay did not improve the uniformity of extruded structures. On the contrary, some left an undesirable pattern in the clay, whereas others caused stratification, excessive orientation and distortion in the finished ware.

Realizing the failure of such stationary devices to solve the problem, insulator manufacturers in recent years turned to other ideas. These resulted in the development of various type dynamic (rotary or vibratory) devices which are attached or inserted in the pug mill barrel to re-mix or otherwise improve the structure of the clay beyond the auger.

One of these mixing devices developed and used by the Lapp Co. on their pugmills is known in Baltimore as a "Delaminator". A copy of this mixer, shown in Photo. #4 was built and attached to a Bonnot vacuum pug mill used for



No. 4 Baltimore Constructed "Delaminator"

the extrusion of station post insulators. This mixing device, placed between auger and nozzle, consist of two solid rings rotating at 30 RPM at 90^{o} to each other. However, since these rings are spaced apart and not interlocked, they rather tend to roll the clay into semi-spheres than cutting up the clay mass.

"Delaminator" Devices

An improvement over this Baltimore constructed "Delaminator" has been made by the Fate-Root-Heath Co. This device called a "Cross Mixer" is shown in Photo No. 5.

Photo. #5 Fate-Root-Heath "Cross Mixer"

It has flat, interlocking rings which not only completely break up the clay column, but which also produce a much desired kneading action on the clay. One of these devices is now attached here on the new FRH vacuum pug mill, making 7" solid slugs for switch and fog type insulators. Sections cut from this pug mill show a uniform structure and are completely free from the "S" cracks shown in Photograph No. 3.

Considerable experimentation in the field of vacuum extruding machines has gone on in Germany during the past few years. One of the pug mill set-ups (Laeis-Trier) called a "spreading Homogenizer". After the clay has left the end of the auger it passes into a chamber (which it completely fills) where it is subjected to the action of paddles rotating in a plane at right angles to the axis of and at the same speed of the auger. Thus, the blank emerges in a direction at right angles to the axis of the auger. The device is claimed to simulate the kneading action of the hands when clay is thrown on the potter's wheel.

We see in his device an effort to eliminate the pug mill auger in the final extrusion.

Double extrusion, i.e. extruding the clay from a regular pug mill into large steel cylinders and extruding from these blanks by a hydraulic ram was used for several years at the Westinghouse (Derry) plant, but due to the required excessive handling and high cost was discontinued about 3 years ago.

Pug Mills with Vibration Equipment

Pug mills have been built in recent years in Germany with attached mechanical or ultrasonic vibration devices with the object to minimize or entirely eliminate auger structures. The idea of applying vibration to plastic clay is to bring the same into a state of thixotropic (temporary softening) condition with the object of increasing the internal homogenity of the structure. A Locke patent (Governeur - U.S. 2,026,782 - 1936) described the pug mill extrusion of plastic clay into a barrel, subject the latter to rapid vibration and then extrude the clay into a final insulator blank. There is nothing on record here that this method was put into practical use.

A new German pug mill (Netzsch), equipped with a grit oscillating with adjustable frequency and amplitude has recently been offered to electrical porcelain manufacturers. This pug mill is shown in Photograph No. 6. It is claimed that this pug mill attachment produces up to 18" diameter blanks free drom distortion, lamination or other structural defects.

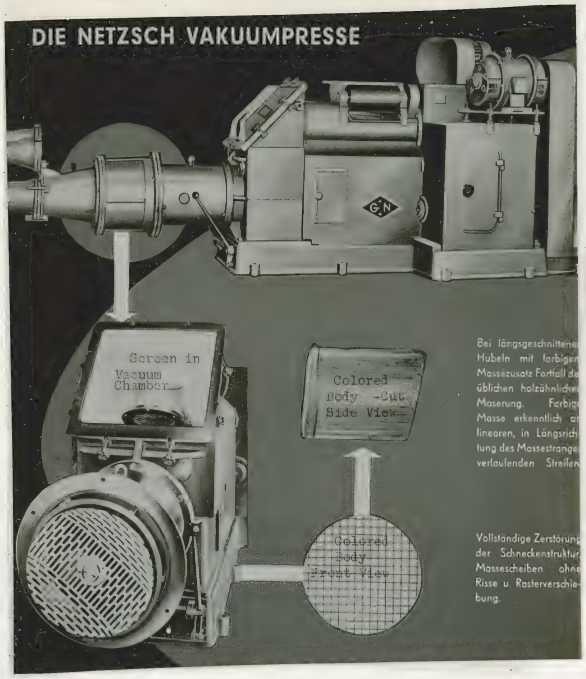


Photo #6.

Here, again, the success of applied vibration depends very much upon the physical properties (plasticity, grain size and mineral constituents) of the porcelain body. As a rule, American high tension insulator bodies, which in contrast to German bodies, containing much higher percentages of plastic (ball) clay, do not become suffiently thixotropic with applied vibration. Experiments made by the General Electric Engineering Department in 1955 to study the effects of ultrasonic vibration upon extruded pug mill blanks showed no noticeable structural changes with applied vibration.

Bonnot Pugmill

with Enlarged

Extrusion Barrel

Figure 1. Bl:4 "Soft Pugmill" and Metal Trough to Receive Cylinder

Figure 2. Extrusion of Blanks for Bushing Section BT279B799-1, 30" O.D., 20-3/8" I.D., 4-13/16 Wall, 30" Length

To Page 75.

Vertical Pug Mills

Of considerable interest is the clay mixing device recently developed by the Ceramic Engineering Section (Spira Flow Unit) shown in photographs 6A and 6B. It consists of a slotted spiral plate which is placed in the pug mill barrel immediately past the extrusion auger. Whereas a former similar but stationary plate did not prove satisfactory due to bad stratification and distortion in the clay column, this new spiral plate, revolving with the auger shaft, has eliminated the above defects. The "Spira Flow Unit" slices the clay delivered from the auger and its tapered slots somewhat knead the clay together again in its forward movement. It is extremely important here that the clay ribbons are again solidified by sufficient back pressure, ie.e. in an enlarged barrel and die restriction, as otherwise weak centers in heavy wall blanks will result.

In recent years the demand for larger size porcelain bushings for transformers and circuit breakers has increased which will require larger and more complicated extrusion equipment. It is reported that in Germany single piece bushings are extruded up to 50 inches in diameter and 12-14 feet in height*.

Formerly such large bushings were made (jiggered) in sections and put together by the slip joining method. This costly method is apparently on the way out in Germany and single piece extrusion from vertical pug mills will soon be the standard method of making such large porcelain pieces. This subject is further discussed in "Joining Insulator Sections", page 103.

Vertical pug mills without vacuum equipment have been used for a very long time here and abroad for the extrusion of sewer pipes. Some of the German vertical extrusion machines, such as the one shown in Photograph No. 7, actually represents a refinement over the conventional sewer pipe extrusion press. From all reports obtained from German insulator manufacturers**, this (Leimer) vacuum extrusion press has produced very large insulator blanks without structural defects. The mandrel to form the holes is attached to the auger shaft. No spider is used. Augers are of a special design, the end section forcing the clay into the center to overcome the usual weakness in pugged blanks.

The Leimer machine is of particular interest. It is not only a single pug mill, but the elevator equipment is of special design and has, in addition to hydraulic equipment, counter weights and pulleys to balance the flow and the weight of the clay column being extruded.

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*Rosenthal Communication 5/5/58
**Stemag Communication 4/29/58

Photo #7 - Karl Leimer Vertical Vacuum Press

American made vertical extrusion machines consist of a combination of two pug mills, a horizontal and a vertical machine. This pug mill assembly is shown in Photo No. 8.

Photo #8 - Fate-Root-Heath PM12 Vertical Pug Mill

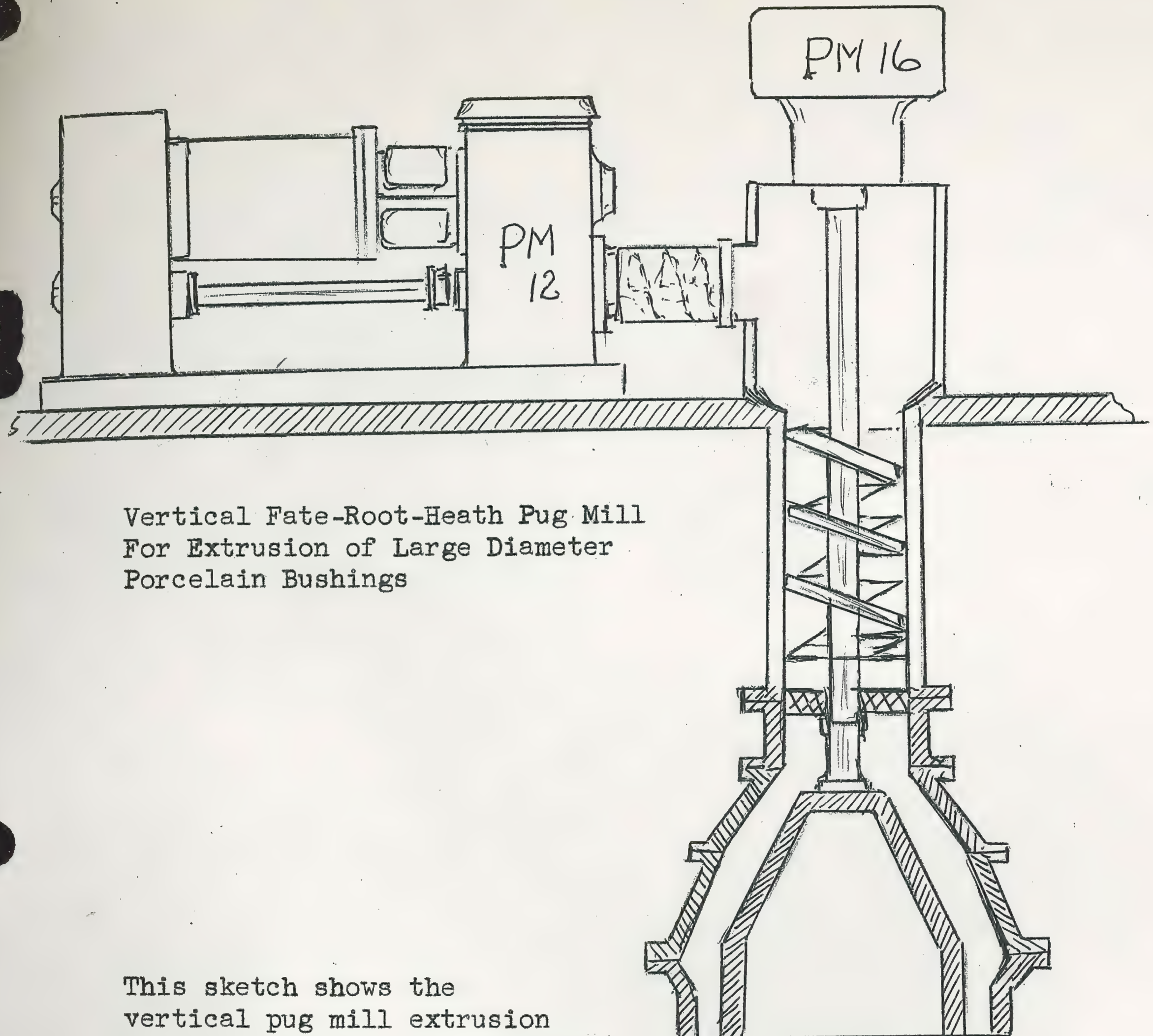
In 1948 the Insulator Department installed one of these vertical pug mills for making 10" suspension insulators. Another (16") PM-16, the larger type machine was purchased in the following year. This vertical pug mill was never installed.

In the making of 10" suspension insulators on this pug mill, the clay was extruded directly into plaster molds which moved around the press on an index table. Great difficulties were encountered with this pug mill in that the clay consistently backed up and plugged the vacuum chamber, which interrupted continuous operation. In addition to this, trouble with auger laminations resulted in manufacturing losses, so that this method of making suspension insulators was abandoned.

Both pug mills were re-sold to the Fate-Root-Heath Company in 1954.

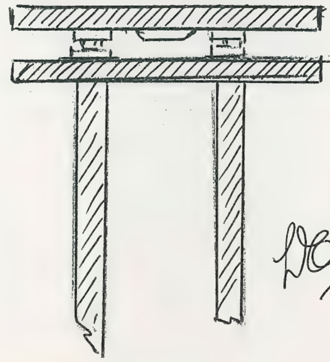
<u>Vertical Extrusion Methods - Lapp Co., Ohio Brass Co.</u>

However, now the Lapp Insulator Company has recently purchased and installed one of these 12" Fate-Root-Heath vertical pug mills for the extrusion of large diameter porcelain bushings. The Ohio Brass Company also has now one of these F-R-H vertical pug mills (PM-16) type, also used for extruding porcelain bushings. The difference, however, in their present methods is that, while Lapp extrudes these hollow bushings on an elevator, similar to sewer pipe practice, Ohio Brass extrudes the clay into large plaster molds and forms the hole on another machine (pull down jigger). See Photograph #5, Page 49. The advantage is that with O.B. methods bushings can be made with either straight or taper hole, whereas by the Lapp extrusion method, only straight hole bushings can be made by a boring operation.



Vertical Fate-Root-Heath Pug Mill
For Extrusion of Large Diameter
Porcelain Bushings

This sketch shows the vertical pug mill extrusion at Lapp according to description given to this writer. The horizontal pug mill is a PM Fate-Root-Heath standard machine having a 12" auger (a). The vertical pug mill, PM-16, has a 16" auger and a slotted plate (b) to subdivide the clay from the auger. The mandrel is attached to the shaft of the vertical pug mill.



Hydraulic Elevator to
Receive Piece During
Extrusion

DOTh
Sept. 1958

Vertical Vs. Horizontal Extrusion

In spite of the considerably higher cost of installation of a vertical pug mill as compared with horizontal pug mills, most of the leading electrical porcelain manufacturers prefer vertical extrusion methods for large diameter bushings for the following reasons:

a. With vertical extrusion no troughs are required, whereas on horizontal machines troughs and inside sleeves are necessary for each diameter piece extruded.

b. The use of a vertical pug mill permits the extrusion of large cylinders upright on a platform where they remain in this position until dry enough for turning. Practically no handling is required. In this upright position blanks will dry faster, as they are all-around exposed to air drying.

c. Horizontal extrusion of large diameter cylinders require clay of extra stiff consistency to prevent sagging. Such stiff clay cannot be obtained by present filterpressing methods. Vertical extrusion allows the use of softer clay, double pugging to increase the stiffness and uniformity of the clay is not necessary.

d. The mandrel to form the hole in the blanks can be directly attached to the vertical pug mill shaft, no outboard mandrel set-up is necessary. Objectionable spiders, formerly used to hold the mandrel, have been eliminated by recent improvements on these vertical pug mills.

Figure 6A - Spira-Flow Clay Cutter (Front View)

Figure 6B - Same Piece, Rear View. This Side Faces the Clay Moving from the Auger.

Pug Mill Operation

The structure in pugged insulator blanks remains unchanged through all subsequent operations and a badly pugged piece usually ends up after firing as a defective and useless insulator.

It is, therefore, obvious that pug mills are kept in proper working condition, that the required vacuum is maintained and that the pug mill operator extrudes blanks free from hard lumps (slugs) and with the mandril properly centered to avoid crooked pieces.

Experience and strict observance of pugging instructions on the part of pug mill operators are necessary to obtain good results.

"Soft" Pug Mill Extrusions

Soft and hard filtercakes should never be thrown together in the pug mill, as it will cause differential flow and laminations.

A good, practical check on the uniformity of the extruded structure of a pug mill blank is to cut off a 1 inch thick slice. By holding this by the edge and waving it gently back and forth like a pendulum, the clay should stretch quite a distance without rupture or showing a spiral pattern.

Dial vacuum gauges cannot be relied on and must be checked periodically and reset with a mercury manometer.

Importance of Clay Stiffness

Physical and flow characteristics of clay bodies are affected both by stiffness and moisture content. Some insulator forming requires soft clay, others require clay of greater stiffness. Therefore, filtercakes of the proper stiffness should be selected before the pugging is started. In many plants, including here at Baltimore, the pug mill operator tests the filtercake stiffness with his thumb and rejects the clay he finds unsuited for a particular job. This method depends much on human element and experience, therefore, some insulator plants use fairly simple devices in the form of penetrometers* (Illinois Porcelain Co., Canadian Porcelain

Control Methods

*Pocket Penetrometer - Soil Test Inc. uses calibrated spring, penetration indicated on scale. Another, similar instrument shows depth of penetration on an Ames dial.

Company) to test the stiffness of the clay before pugging.

There is a difference between the stiffness of a filtercake clay and the stiffness of the same clay after pugging. The pugged clay is usually softer due to the heat produced by friction and the thixotropic effects in the pugging operation.

A very practical apparatus, known as "Locke Stiffness Tester" was developed at Baltimore about 30 years ago. It is still used in the plant to check the stiffness of pugged blanks. The apparatus is shown in the attached Photograph #1.

Photograph #1 - "Locke Stiffness Tester"

In making a test a small disc 1-3/4" diameter and 1/2" thick is cut from a pugged blank and placed on the bottom plate. The apparatus is then set in upward motion by a motor driven crank, thus compressing the clay disc. The amount of compression or the pounds of force transmitted to the top platen is recorded as the stiffness measurement.

The relationship of clay stiffness and moisture content of the No. 740-1 plastic body, as determined on the Locke Clay Tester is shown in diagram, Figure 1.

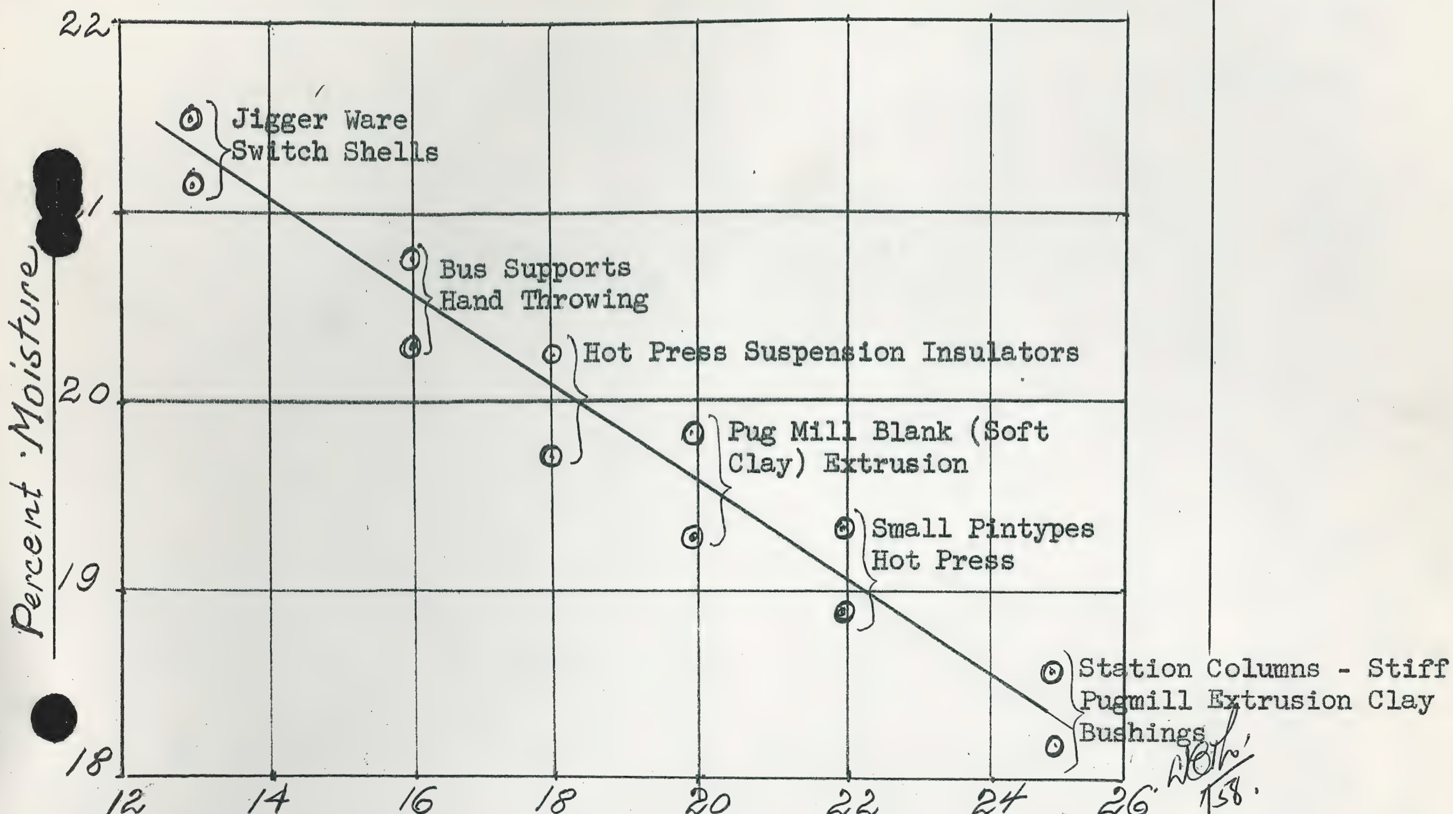


Fig 1.

Clay-Water Consistency for Plastic Forming

A much stiffer clay, prepared from pulverized body mixed in Muller type mixers, is extruded on so-called "Hard Pug Mills". These are actually the same horizontal vacuum pug mill but with much heavier type motors (45 to 150 HP). For testing the stiffness of this clay a "Drop Gauge", i.e. a heavier type of penetrometer is used. The moisture in such extrusions is as low as 14% for smaller and 17% for the largest bushings, up to 28 inches in diameter.

"Hard Pug Mills"

Some of the medium and smaller type bushings are machined almost immediately after extrusion, i.e. in "leather hard" state by a method known as "skiving". Usually a steel tool shaped

to the contour of one-half of the desired bushing is employed. Special built, semi-automatic or fully automatic machines are built which combine skiving and counter boring operations. Such machine is shown in Photograph #2. The moisture content and stiffness are critical; pieces with 13% moisture are too hard and with 15% too soft for finishing on such skiving machines.

Photograph #2. Automatic Finish Machine - Capable of High Output at Minimum Cost

Chapter VIII - Finishing Operations

In the finishing of insulators from hot plunged or extruded blanks, various methods are employed, such as trimming, wet or dry turning, drilling, grinding, etc., each method depending upon the design, size and the amount to be manufactured.

<u>Wet Turning</u>

As has been mentioned briefly in previous chapters, suspension, pin type and switch type insulators are finished by hand operation in leather hard state. The tools used may consist of a simple "U" shaped wire cutter, a sponge, a flat knife and a soft white rubber pad to remove the flash and to smoothe the surface of the insulator.

<u>Suspension and Switch Types</u>

Semi-automatic machines have been built to cut grooves and to finish to final shape more complicated designs. These machines operate more or less on the principle shown in the attached sketches. Figures 1 and 2 namely by a plurality of wire cutters and curved strip of thin steel which move against the leather hard body and, by its shaving action remove the surplus of the clay.

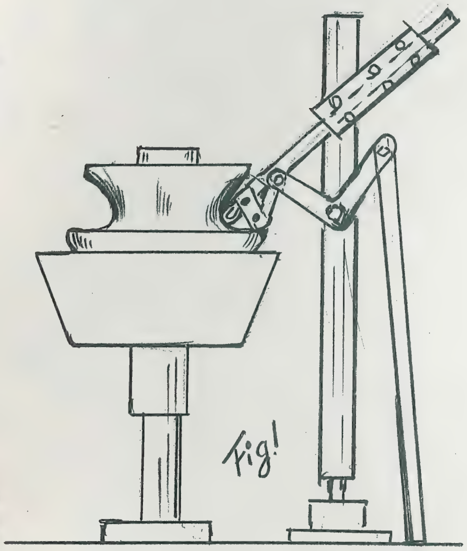


Fig 1

Fig. 2

<u>Pin Types, Spools, Etc.</u>

Smaller pin type insulators and spools, which are large production items, are finished to final shape in leather hard state on automatic machines. Such automatic machines are in operation at G.E. Baltimore and Victor Insulator plants. The hot pressed blanks, after conditioning

to a leatherhard state, are mounted on a revolving vertical or horizontal table so indexed that each spindle stops automatically at each cutting station long enough for the finishing opeation, to be formed in sequence, is achieved. From 5500 to 6000 pin type insulators can be finished in a day's shift.

Apparatus Bushings

Apparatus porcelains of all types were, in earlier years of the industry, thrown and finished by hand operations on the jigger wheel.

The wet turning of large bushing shells at the Ohio Brass Company's plant is done by hand operation. The operator uses a carboloy tipped tool guided by a type of pantagraph which accurately imparts the shape of a template to the insulator surface.

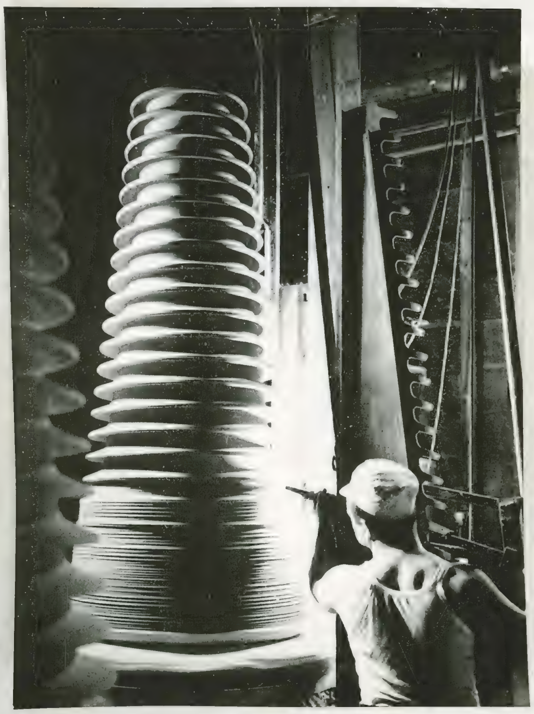


Figure 3. Finishing Large One-Piece Bushings at O. B. Plant

The Ohio Brass Company is the only plant in this country where such large single-piece bushings are finished by this method. The forming of the blanks by vertical pug-mill extrusion in plaster molds and the finishing, glazing and handling is still largely a matter of operators individual experience and skill. Furthermore, the hazard involved and labor costs are very high as compared to those of cast or extruded, glazed-joined or slip-joined sectional bushings.

<u>Automatic Finishing Machines</u>

In recent years German manufacturers of ceramic machinery*, encouraged by the increasing demand for Langstab (long-rod) insulators, have constructed automatic green finishing machines.

Figure 4. Gebruder Netzsch (patented) Automatic Green Finishing Machine

Main feature of this machine is the control panel equipped with oil hydraulic movements. The cutting tool moves in two directions at right angles, i.e. vertically and horizontally to finish the insulators including the undercut petticoats. Finished pieces 72" high - 17" diameter.

*Netzsch and Dorst Machine Co's., Bavaria

The largest diameter piece that can be turned on these machines is presently only 15 inches, up to 8 feet in height. The speed can be varied between 44 and 220 RPM.

With the larger transformer housing now manufactured in Germany (12 ft.-14 ft. high and up to 50 in. in dia)* it may be expected that similar, but larger size green finishing machines will be built in the future. There are certain advantages in turning pieces in leatherhard state. First, the drying cycle is considerably reduced because large and heavy wall blanks must be dried slowly to about 3-4%, which usually takes 2-3 weeks. By turning such pieces in leather-hard conditions, i.e. with 10-12% moisture, about 40-60% of the mass is reduced, allowing faster final drying. Secondly, no dust is created by dry-turning and none of the dust collector equipment is required.

The turning of insulator blanks dried to 3-5% moisture on profile lathes has become the standard method in every American electrical porcelain plant. This method had its beginning around 1920**. It consists in its simplest form of mounting a cylindrical blank on a lathe spindle and moving a pendulum supported cutting tool along a guiding template mounted above the work. An illustration of an earlier type profile lathe set-up is shown in Sketch, Figure 5.

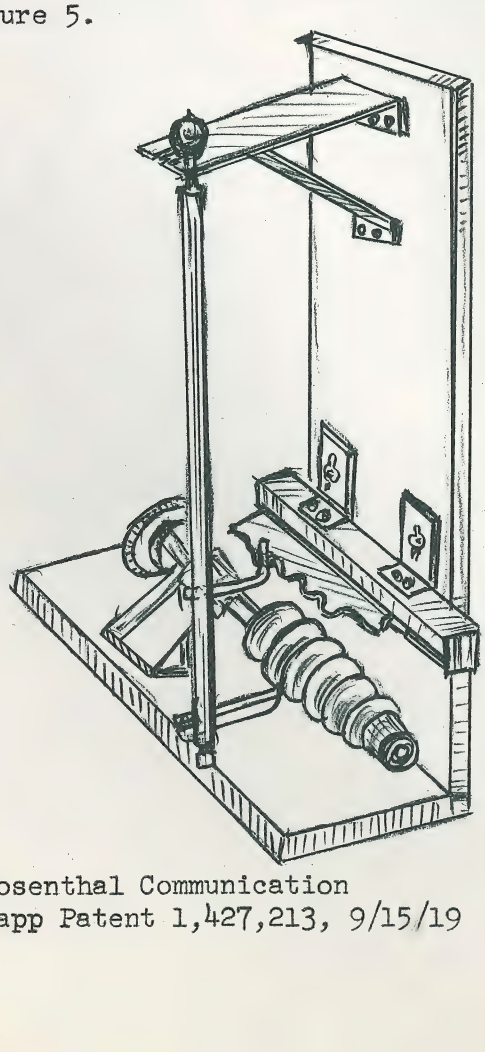


Fig 5.

*Rosenthal Communication
**Lapp Patent 1,427,213, 9/15/19

In later years the tool steel was replaced by long lasting carboloy tool tips. The single pendulum tool holder was also replaced by an overhead trolley and this arrangement including the above-the-work profile is found today in most American porcelain insulator plants.

The G.E. Schenectady plant in 1927 adopted a somewhat different, and what is considered improved, profile turning equipment. This is shown here in photograph Figure 6. The template is mounted at the base of the lathe. The operator moves the carboloy cutting tool, mounted on the opposite side, by turning a roller with his fingers. The lathe is built into a dust collector booth and the chips are thrown downward on a belt conveyor. In this way a battery of lathes are grouped together. The advantage of the G.E. profile lathe equipment over the older design lies in the fact that the clay cuttings and the dust fly away from the operator and that no trolley-tool bar interfers with his work. The same type of profile lathe is also used for dry-finishing large cast bushing sections.

Figure 6. Porcelain Bushing Being Turned on G.E. Profile Lathe.

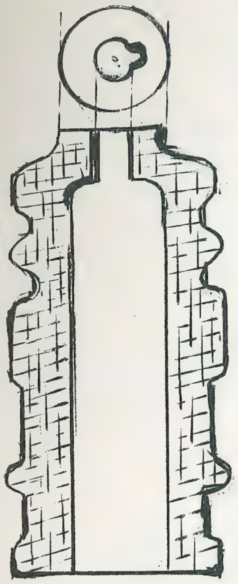
Large cast bushing sections are bored on the inside before the outside contour is turned. This operation is shown in Figure 7. Bushing sections up to 46 inches outside diameter are finished by hand turning. Vertical profile turning of such large completely dried pieces has not been practical on account of the chipping and shattering of the dry body.

Bushing sections up to 29 inches outside diameter are turned on the horizontal profile lathe after the inside hole has been bored on the above machine. This lathe operation is faster and it produces better finished and more accurately machined pieces.

Figure 7. Boring and Finishing Large Cast Bushing Sections

The manufacture of porcelain bushings have two different holes or blind ends can only successfully and economically be made by extruding the blanks with the small hole and boring the large hole on a vertical boring machine, such as shown in Photograph, Figure 8. The blanks are dried to approximately 3% moisture (Illinois), 4-7% gives best results with the Baltimore wet-process body. Pieces with a

higher moisture, grind rather than cut, whereas pieces completely dried chip badly during boring operations.



Vertical boring machines assure drilling of perfectly centered, straight holes in clay blanks.

Figure 8. Vertical Boring Machine

The machine shown is hand operated (Victor) but other such vertical boring machines are equipped with automatic hydraulic or pneumatic feed and stroke. (Baltimore, Illinois Porcelain). Such counterboring, one of many secondary operations is performed before turning the pieces on the profile lathe. Other shapes, however, are counterbored and notched after turning.

A characteristic of both hard and soft clay extruded from pugmills is the tendency to bulge in firing in the direction of extrusion, regardless of which way the porcelain is fired. The reason for this is that during pugmill extrusion the plastic clay moves faster in the center of the column. With many insulator designs, this is no serious defect. However, in some it causes some displacement of petticoats, especially if the insulators have been made in two sections and, as is customary, joined by glaze.

In order to prevent such displacements, the blanks, during extrusion, are marked by an arrow (⟶), so that the lathe operator always can place and turn the blanks in the same direction on the lathe.

Wet Turning Versus Dry Turning

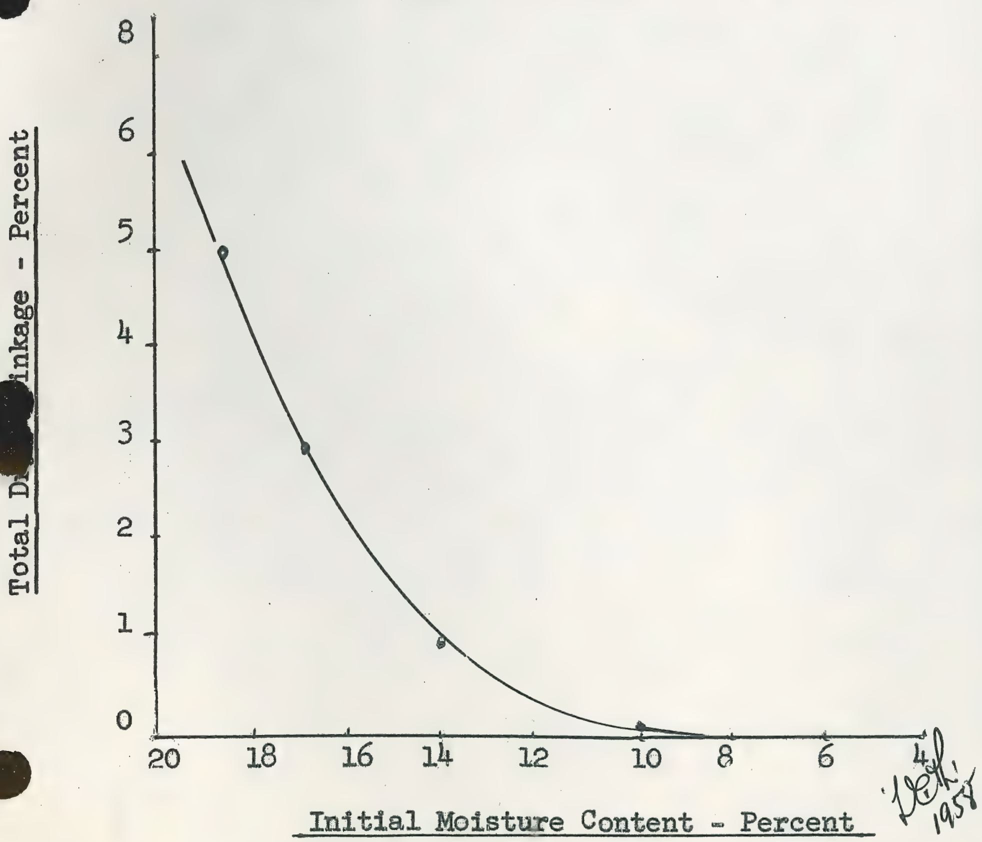
One of the reasons why insulator manufacturers have changed from wet-turning to dry-turning lies in the fact that dry turned pieces have no shrinkage after turning and, therefore, closer dimensional tolerances are possible on dry-turned pieces.

However, completely dried blanks are very hard and tend to chip during turning. It has been dound that slightly damp blanks not only produce a better finish but also that by utilizing blanks in this condition greatly speeds up production due to reduced drying time.

Moisture Control at Turning Important

One important question is, how much moisture can be left in the blank at the turning stage without getting additional drying shrinkage? Experiments with pugged blanks dried to and turned with various amounts of moisture, have shown that drying shrinkage was completed at 9.5% moisture and that variations in length below 10% was negligible, but dimensional variations rose rapidly above this point. Total drying shrinkage versus moisture content is shown in the following diagram.

Drying Shrinkage Vs. Moisture Pugged Blanks



In order to avoid shrinkage variations in turned insulators, moisture control became necessary and manufacturing instructions were issued, specifying that blanks for dry finishing should contain 5-9% moisture, which gives pieces somewhere between a bone dry and leatherhard condition. The outside appearance of such blanks is usually near white.

Form Grinding (FOD)

This method of finishing insulator shapes from pugged blanks or such made in plaster molds on a Crossley pulldown jigger is known here as "FOD" - Outside Diameter Form Grinding. It was widely used at the Schenectady Porcelain Plant, adopted from a method originated by the J. D. Company for grinding porcelain spark plug cores.

Form Grinding (FOD)

The equipment required for FOD grinding is quite simple. The grinding tool consists of an abrasive (carborundum) wheel which periphery is provided with grooves and ribs to form a pattern conforming to the outside shape of the insulator to be made. This form grinding method is extensively used in the manufacture of steatite and high alumina insulators (lathe and abrasive wheel) and the contour grinding of a porcelain bushing is shown in Photograph, Figure 1.

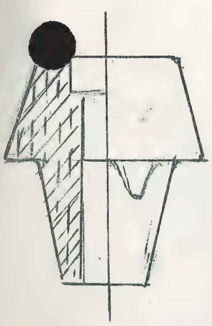


Figure 1. FOD Grinding Lathe - built into dust collector. Two pieces are ground in one operation.

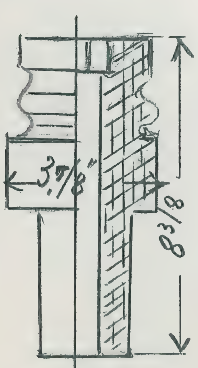
Blanks must be dried uniformly throughout to less than 3% moisture, as damp pieces will clog up the wheel.

The operator places a blanks upon the mandrel. A lever is first moved against the revolving abrasive wheel. This grinds off a section as a starter. Then, the operator slowly turns the hand wheel to follow up and by several faster revolutions of the wheel completes the grinding operations. At Schenectady insulator shapes up to 12 inches long and 4-5 inches in diameter were contour-ground on such machines.

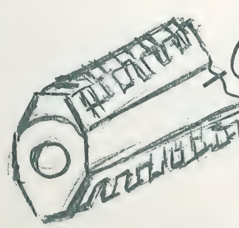
Depending upon the size and shape of the insulator, 40-60 percent of the body is removed as fine dust. This dust was at the Schenectady plant re-blunged and added as a slip to the virgin plastic body. At Baltimore, the dust is put into the silo system and remixed for further plastic extrusion in Muller type (Lancaster) "dry-mixing" machines.

In this form grinding operation only the outside contour of the insulator is possible, all other operations, such as counter-boring or drilling holes, or slotting, must be performed on other grinders or drill presses.

Smaller bushings, such as shown in Sketch A are now faster and more economically produced on wet-finishing machines such as shown in Photograph #2, page 83. By form grinding, only 600-700 uncomplete bushings, requiring several additional operations, are produced per shift, whereas 2200 complete pieces are produced by wet finishing on the above automatic machine. The blanks for these jobs must be extruded in the "hard" pugmill, i.e. very stiff clay to hold the hole to close dimensions. Bushings such as shown in Sketch B can be made quite economically, 350-375 pieces can be finished per shift.



B


C

Threaded resister unit porcelains, such as shown in Sketch C and spiral coil forms are extruded to exterior shape on a pugmill and the spiral grooves ground into the piece by an assembly of thin carborundum wheels. Form Grinding does not produce the same smooth finish obtained in wet-turning operation. This often leads to pinholes and other defects on the glazed insulators. The present trend at Baltimore is to build more special (automatic) machinery to turn, in latherhard condition, the remaining number and types of bushings now made by this FOD dry grinding method.

Hydrostatic Forming Methods

Hydrostatic Forming

Hydrostatic forming methods have been employed in the manufacture of alumina porcelain spark plugs for more than 20 years. Due to the non-plastic character of these ceramic bodies, plastic extrusion is impractical and hydrostatic pressing is the only method that produces pieces of uniform shrinkage and density.

In the electrical porcelain industry, as far as is known, only one manufacturer has employed hydrostatic pressing, apparently quite successfully*. The shape and size of bushings made in larger production quaitities has been that shown in Sketch, Figure 1. The blanks for these bushings were pressed in rubber bags similar to the one shown in Sketch, Figure 2.

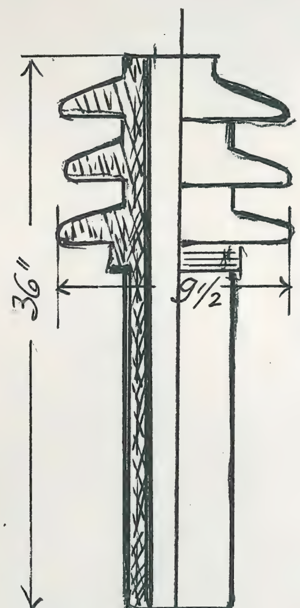


Fig. 1

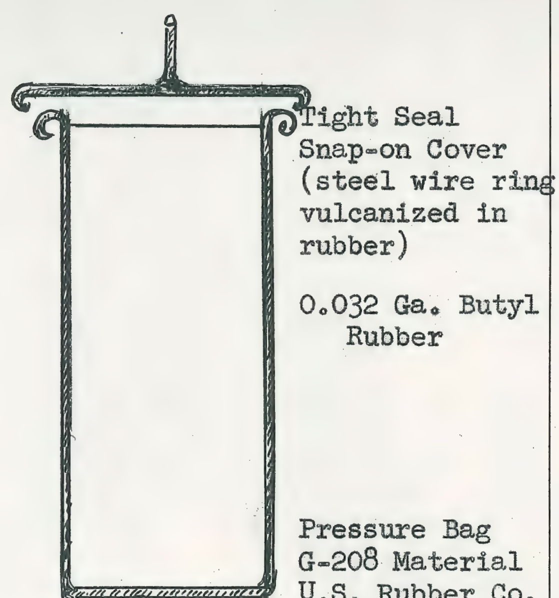


Fig. 2

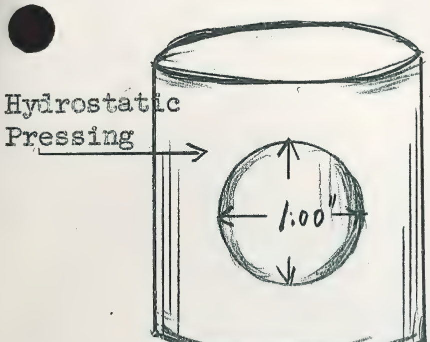
The basis for the hydrostatic technique is the principle of uniform pressure transmission, i.e. Pascal's Law. In operation, a pulverized ceramic body, containing only a small amount of moisture (3-5%) is sealed after evacuating the air, withing a rubber or other liquid-tight envelope and immersed in a fluid which is subsequently pressurized in all directions.

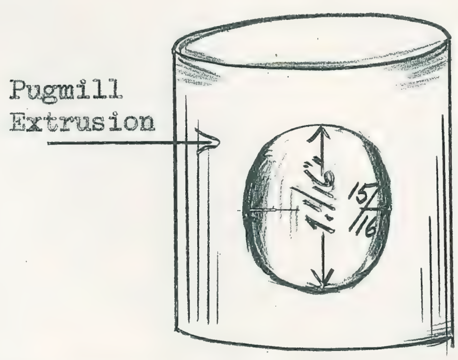
*Jeffrey DeWitt Co., Kenova, W. Va.

Hydrostatic pressing has in recent years found considerable application in pressing or re-pressing blanks for high alumina bodies and other high-density ceramic specialties. Currently, high alumina shapes up to 7" in diameter and 14" long are pressed by hydrostatic forming methods*. For pressing some ceramic-metal powders, pressures up to 35,000 lbs. psi have been used.

Extensive experiments by the Insulator Department and the Transformer Laboratories at Pittsfield have been made, showing that with 5000 lb. psi pressure applied, hydrostatically formed shapes have a very uniform shrinkage and density. The pressed pieces are readily machineable, since the ceramic powder is formed virtually dry. Long drying cycles, as necessary for plastic extruded pieces are not required. Pugged insulator blanks usually shrink differently in length and diameter. This often results in strains and distortion in shape of the fired insulators.

Hydrostatically pressed blanks are free from such shrinkage variations and distortion, as shown in the following sketches, Figures 3 and 4. Electrical and mechanical properties of hydrostatically formed insulators were equal to those obtained on plastic extruded insulators.





	Firing Shrinkage	
Diameter	9.2%	10.0%
Length	9.3	6.5
Fired Density	2.42	2.38

Figure 3. Figure 4.

*American Lava Corp.

Microscopic examinations made of fired thin sections cut from these pugged and hydrostatically pressed cylinders showed non-plastic grain orientation (flint) to be practically absent in the piece formed by hydrostatic pressing.

Considerable particle orientation was found in the pugged piece, i.e. parallel to the direction of plastic extrusion. Differential plastic flow and the grain orientation produced by this effect are known to be responsible for much of the drying cracks, warpage and firing cracks in ceramic ware.

There are several advantages to the hydrostatic forming method, the primary one being that it makes it possible to produce ware of uniform density and shrinkage. Another economical advantage is that hydrostatically formed blanks can be machined to final shape almost immediately after pressing, requiring no lengthly drying treatment.

However, the cost of necessary equipment, such as high-pressure tanks, pumps and rubber molds, especially for large diameter shapes, is very high and it would seem, therefore, that this method will only find an application for certain types of porcelain insulators that cannot economically be made by any other conventional means.

Chapter IX. Drying and Firing Shrinkage

Electrical porcelain, like all other clay containing ceramic bodies, shrinks in drying and firing and proper allowance must be made for such shinkages to obtain pieces meeting required drawing dimensions. An illustration of such shrinkages has already been given in photograph, page 54, showing the dimensional reduction in the size of a 10" suspension insulator from the plastic molded to the fired state.

Mechanics of Drying Shrinkage

Drying shrinkage begins with the evaporation of the moisture from the plastic molded piece and the drawing together of the clay particles. This shrinkage continues until all the grains come into close contact. But since they do not fit together perfectly, there will still be some pores left, holding a residual amount of the moisture (pore water), which eventually can only be completely removed by heating the body up to 100°C (212°F), i.e. the boiling point of water.

The amount of drying shrinkage is very much affected by the amount of moisture in the body. As shown in the diagram "Moisture vs. Drying Shrinkage", page 92, the drying shrinkage in pugged blanks from the 740-1 plastic body ceases when all but about 9% moisture is removed in the dryers, which allows all blanks below this moisture to be turned without additional drying shrinkage.

It is the practice in the ceramic industry to define shrinkage as a percentage. Linear drying shrinkage at the Baltimore plant is calculated according to the following formula:

$$\text{Percent DS} = \frac{W - D}{W} \times 100, \text{ where}$$

W is wet length molded piece
D is dry length after moisture removal

Mechanics of Firing Shrinkage

Firing shrinkage in a porcelain body is caused by pyro-chemical reactions, such as dehydration, recrystallization and vitrification during the firing process.

A simple illustration showing the characteristic dimensional reduction in the size of a dry-turned porcelain bushing after firing is presented in Photograph, Figure 1.

Figure 1. From Left to Right (Pugged and dried blank
(Bushing turned on profile lathe
(Glazed and fired insulator

In electrical porcelain plants percent firing shrinkage is defined as the ratio of the difference in dimension between dry and fired state divided by the dry dimension, multiplied by 100. Expressed as a formula:

$$\text{Percent FS} = \frac{D - F}{D} \times 100, \text{ where}$$

D is dry length of turned piece,
F is fired dimensions.

In determining this percentage it has also been the practice in making a new piece to seek a similar one on which shrinkage data has been established and to use this information as a guide for the new piece. This more or less empirical method has been proven successful, but it required dimensional re-checks and sometimes changes in turning profiles, etc., all adding up to a possible delay in the

manufacturing process. The Engineering Section has now prepared tables for a faster solving of shrinkage problems. The factory also makes use of what is known as "Shrinkage Scales", such as 1/10 (10.0%) scale for dry turning cast bushings, 1/12 scale (8.5%) for dry turning pug mill blanks and 1/8 (12.5%) scale for making plaster molds for plastic, ram-pressed cutout boxes. These differences in shrinkage come from the different forming methods employed, but other factors, such as variations in raw materials, the fineness of flint or feldspar and the duration and temperature of firing may also become contributing factors in shrinkage variations.

In wet-process porcelain a variation of 1/32 inch to the inch (3%) above or below the drawing dimension should be anticipated. Where extreme accuracy in the length of a finished insulator is required, as in certain types of high voltage bushings and switchboard insulators, the end surfaces must be ground on a carborundum wheel.

Chapter X. Joining Insulator Sections

Porcelain bushing shells of large dimensions or such of complicated design, that cannot be made in one piece, are made in several sections which are joined with body slip before firing or with a special glaze in the firing process.

Slip-Joint Methods

Joining porcelain sections in leather-hard state with body slip is a well known old art in Europe' ceramic plants. Casting of large bushing shells as common in U.S.A., either in sections or as a single piece, is practically unknown in Europe.

In the U.S.A. only one porcelain plant, the Lapp Insulator Company, has adopted the European method of slip-joining, both in the making of electrical porcelain bushings, as well as chemical porcelain ware. Slip-joining (i.e. sticking-up) of cast sectional pieces of sanitary porcelain is standard practice in American whitewares plants. The body slip is usually flocculated with a small amount of NaCl which slows down the setting and thereby prevents drying cracks.

In Europe and in the Lapp Insulator plant, bushing shells are usually made by first jiggering the individual sections in plaster molds in a manner similar to jiggering switch insulators. After allowing these sections to obtain a leather-hard condition, they are turned on the jigger to "green finish" dimensions. Then, each section is built up on top of each other, first by slightly roughening the surface to be joined with a comb-like tool and then by coating the surfaces with a layer of creamy consistency body slip. In some cases, the operator slightly moves the section back and forth, whereas in other cases he just applies a gentle pressure which squeezes the surplus slip from the joints. This slip is removed with a wet sponge. In firing, the sections vitrify together, and if properly done, slip-joined bushings come from the kiln as single piece porcelains with no or very little indications of joined areas.

The following photographs, Figures 1 and 2, taken in a German insulator plant, illustrate the steps of making a slip-joined porcelain bushings.

Figure 1. Jiggering Individual Sections Sometimes Up to 12 Required to Make a Bushing.

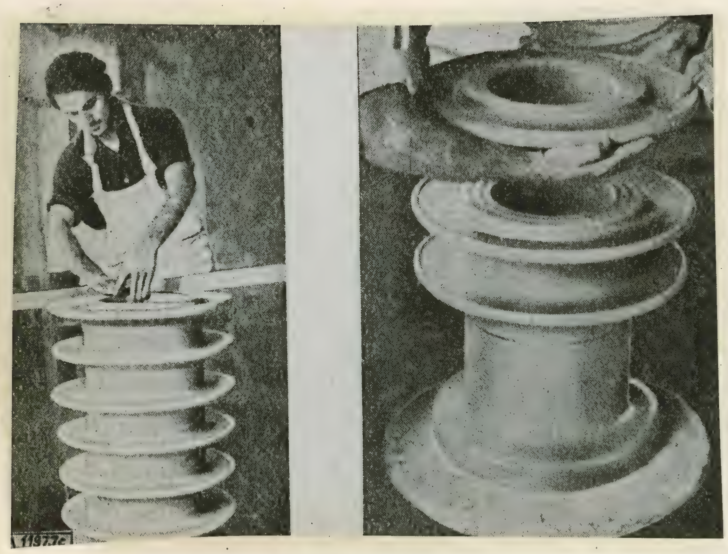


Figure 2.

Right: Roughened or Grooved Section Coated with Slip, Operator Setting Down Section By Section.

Left: Adjusting and Lining Up Sections, Remove, (Sponge) Away Slip and Smoothen Joined Area with Flat Tool (Whalebone).

G.E. Experience With Slip-Joined Insulators

It is of utmost importance to have the sections of uniform leather-hard stiffness. The slip consistency is also critical; a watery slip causes drying cracks, a very stiff slip will not stick.

With the writer's supervision and practical experience in German insulator plants, some experimental slip-joined bushings were made in the Schenectady Porcelain Plant. In 1929 several bushing shells, Dwg. 589970, were made by jiggering the individual hoods in plaster molds and, in leather-hard conditions, joined with plastic body slip. Again, in 1943, two sample bushings K-3981345, as shown in sketch Figure 3, were made by hand throwing blanks on a pottery wheel, turning ("green finishing") the five sections and joining these with plastic body slip in a manner herewith described.

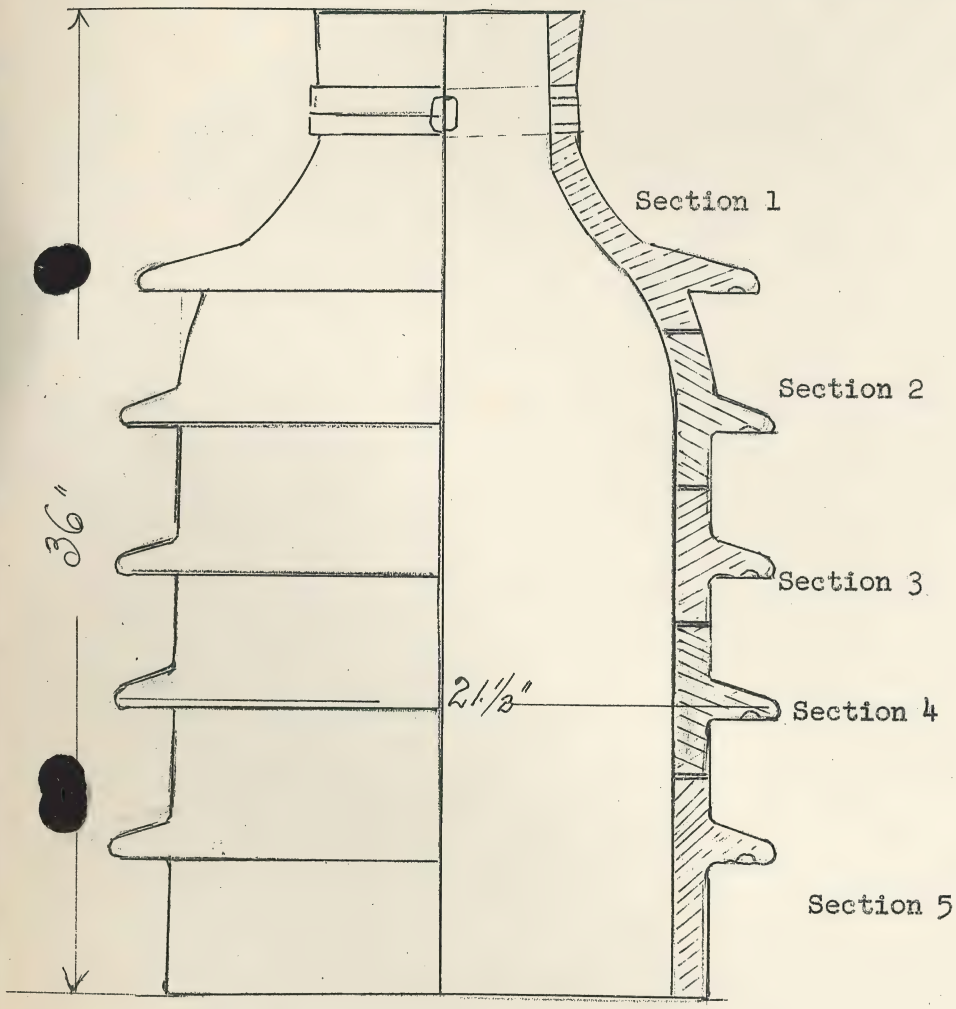


Fig. 3 Slip Joint Wetprocess Bushing

In order to avoid much handling the piece after joining and finishing, the bushing was built-up on a sanded porcelain and fire clay washer and sprayed with glaze and then transported in the kiln in this position.

The fired bushings looked sound, no cracks or joint marks visible. With no special test equipment available, the fired insulators were dropped several times on a padded mat on the floor. No breakage occurred in this impact test.

Due to much higher manufacturing costs as compared to cast sectional, glaze-joined bushings, no furthe work was done in this field.

The writer had also experience with slip-joint cast bushings, such as the typical German design shown in sketch Figure 4. Here, the two sections were cast to "green finish" dimension, making turning operations unnecessary, except removing casting fins and cutting cementing grooves.

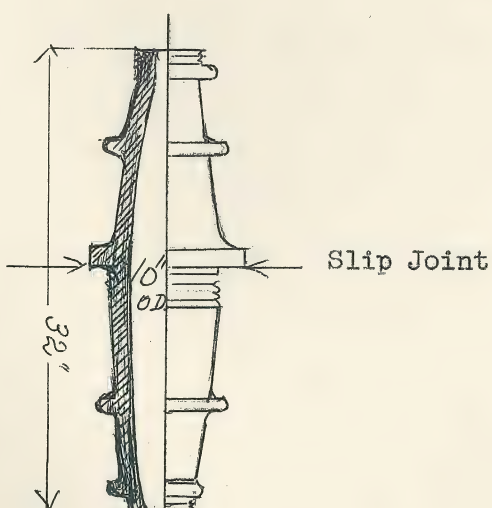


Figure 4. Typical German Design Transformer Bushing

These slip-joined bushings met all electrical and mechanical requirements, showing that if the work is carefully done a perfectly sound, one-piece porcelain will be the result.

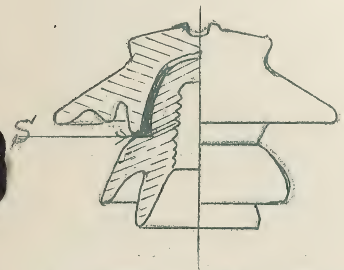
In spite of the high labor requirements and costs, the Lapp Insulator Company has been over the years perpetuating the art of making slip-joined insulators, but also making a line of complicated and intricate shape chemical porcelain ware, for which this process is an absolute necessity.

Glaze-Joint Methods

Manufacturing experience at G.E. Porcelain Plants with sectional bushings joined by glaze in firing extends over more than 40 years and it has proved to be the most economical way to make such large porcelains. The Westinghouse Company, the only other electrical porcelain manufacturer, casts single piece bushings up to 7 feet high, but larger pieces are cast in sections which are joined by a glaze.

Glaze-joined multiple part high voltage pintype insulators were for many years manufactured in a German insulator plant. The idea was to eliminate Portland Cement assembly which in earlier days, before resilient coatings (Sarco) between the porcelain parts were adopted, gave considerable trouble with the cracking of the porcelains due to cement expansion.

Sketch, Figure 5 shows a glazed-together German high voltage pintype insulator. The bottom section has a shoulder (S) which prevents shifting. Both sections must be turned to close dimensions so that only a narrow air space between the head and bottom section is left. Otherwise, the parts are completely sealed with glaze. In this German factory, thousands of such insulators were made by this glaze-joint method. The strength has been high enough to bend the iron bolts without the head section being torn off in the cantilever test.



125 Kv German glaze-joined Pintype Insulator. Figure 5.

This method of joining sectional pintype insulators has not been adopted by American insulator manufacturers. Experimental glaze-joined pintype insulators (Locke No. 1044) made at Baltimore demonstrated the difficulty of turning and firing these insulator sections to a close enough match. The fired insulator showed poor alignment of the top and bottom part and further attempts to make such insulators by this glaze-joint method were abandoned.

The widest application of the glaze-joining method lies in the manufacture of large sectional bushings, made either by the cast or plastic extrusion (pugged) methods.

A typical example of a sectional bushing is shown in Figure 6.

The sections 1, 2 and 6 are cast in separate plaster molds, whereas sections 3, 4 and 5 are cast in the same mold.

The hazards in the manufacture of such large bushings by making these in sections, instead perhaps in a single piece, is greatly reduced. If one section becomes damaged in handling before firing it can be replaced easily without losing the entire bushing. Glazing and kiln loading is also much easier with sectional bushings.

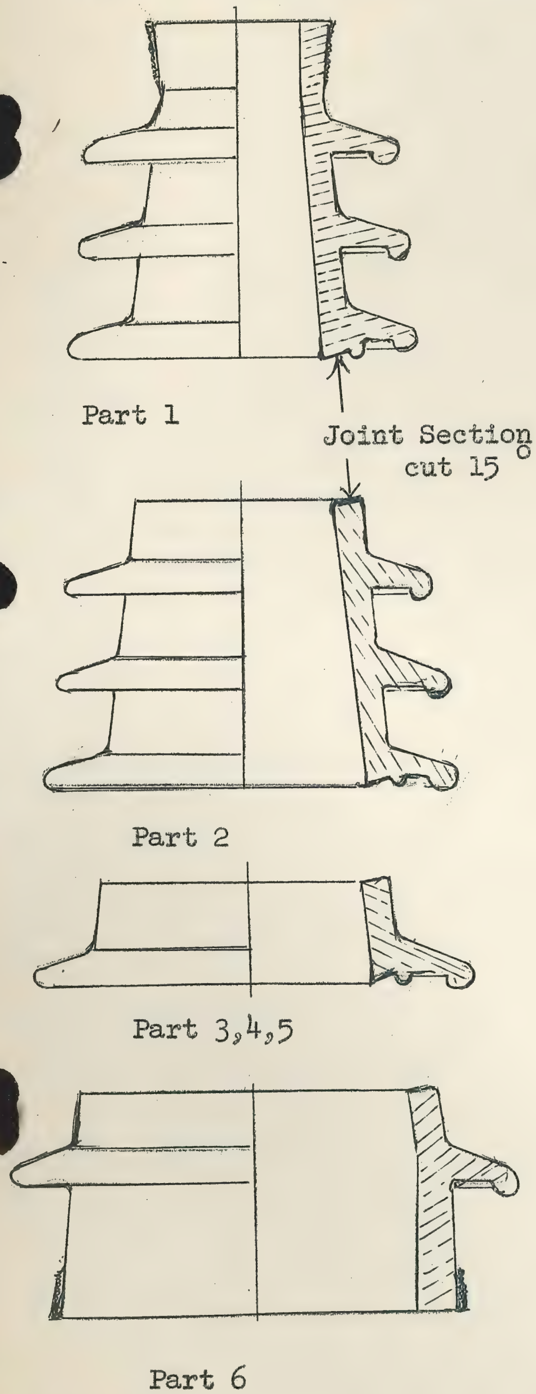


Figure 6. Bushing Shell 468474 -
Fired Height 48 Inches
Largest Diameter 20 Inches

In every respect the manufacture of such glaze-joined bushings requires much experience and careful workmanship. Manufacturing losses in this field are costly and much time is required to make up for lost pieces.

Importance of Joint Angle

For instance, the turning of the top and bottom section to a 15 degree angle is very important. Figure 7 shows a properly cut top and bottom section and also the required clearance that must be provided for variation in shrinkage of the section in firing.

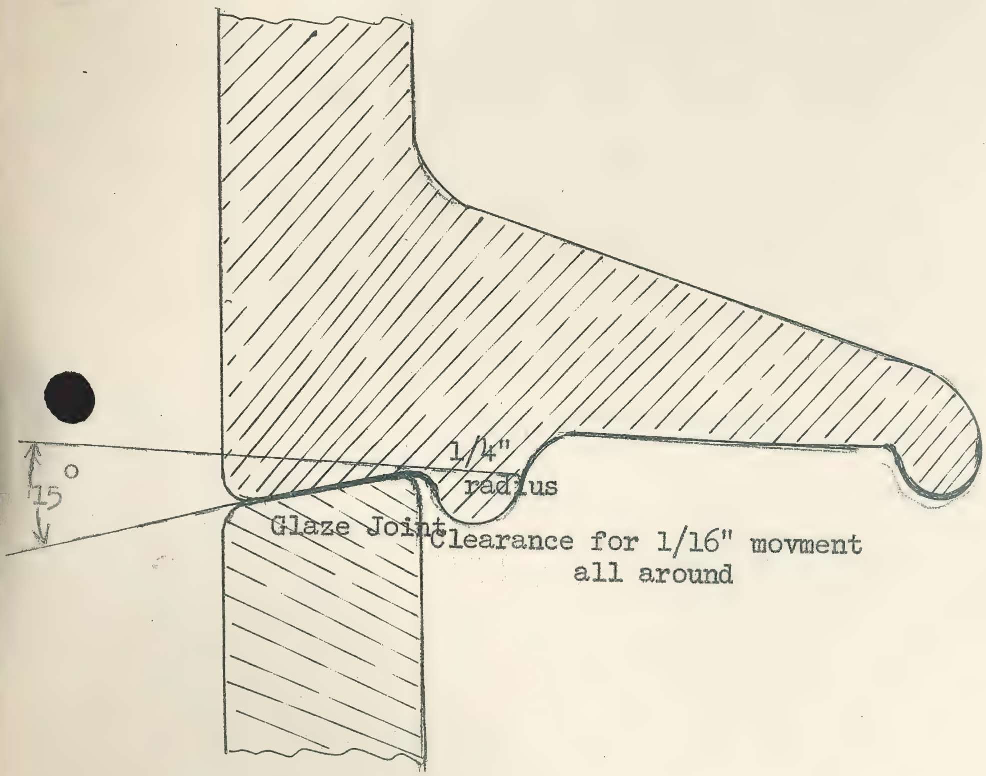


Figure 7. Joint Section Bushing Shell No. 468474

Special Joint Glazes

A special joint glaze is used at Baltimore and also at the Westinghouse plant. These glaze compositions will be described in a later chapter on "Glazes and Glaze Application".

Mechanical and Electrical Tests

Fired glaze-joined bushings are subjected to a routine transverse test. In this test a mechanical pressure up to 12,000 lbs., depending upon the size of the insulator, is applied to four locations (T & AP Department Standing Instructions). The actual breaking strength of a bushing

having good glaze joints is about double the value required in the test specifications. As a matter of fact, ultimate breakage will more often than not occur in the solid porcelain outside the glaze joints.

In good glaze-joined bushings, an average fiber stress value of 1000 lb. psi is usually obtained. The average fiber stress value in single-piece porcelains is between 1500 and 1600 psi.

Mechanical Strength

Slip Joints

vs.

Glaze Joints

The Baltimore Ceramic Laboratory in February 1957 prepared and tested solid, slip-joined and glaze-joined 4 inch diameter test cylinders. Test values (Modulus of Rupture) showed that slip-joint cylinders were 17.5% stronger than glaze joined cylinders and solid porcelain cylinders were 76% stronger than the glaze-joined samples.

Both the Schenectady and Baltimore porcelain plants have over a period of 40 years produced thousands of sectional glaze-joined porcelain bushings and these have and are still giving satisfactory performance under all kinds of conditions.

Causes of Mechanical

and

Electrical Failures

When occasionally bushings have failed, i.e. broke below the specified mechanical or requested electrical test values, the causes for such failures can usually be found in

1. Improperly cut, i.e. poorly matched joint sections,

2. Joints too tight and without sifficient cleanrance, hoods may snap under strain. If joint section too wide, sections will shift with fluid glaze, bushings lean or warp.

3. Insufficient amount of glaze. The proper amount is 26-28 mils each side when tested with glaze thickness gauge. An excessive amount of glaze will run out of the joints and give an unsightly appearance. Furthermore, an excessive amount of glaze will also develop a honey-comb structure which not only will give low mechanical strength but low electrical strength of the glaze joints.

Electrical tests have occasionally been requested by customers. In this test the bushings are filled with water and the power is applied by placing a chain around each section. Such tests have shown that good glaze joints will not puncture below 90-95 IV for a 1 to 1-1/8 wall thickness.

In recent years German insulator manufacturers have abandoned the method of slip-joining jiggered sections due to increasing labor costs and shortage of skilled workers. Single piece bushings for 380 and 400 KV transformers and circuit breakers up to 16 feet high and 42 inches in diameter, as shown in Figures 8 and 9, are made by vertical pugmill estrusion and fired in special kilns*. The making, turning, glazing and handling of such large porcelains represents one of the greatest achievements of the electrical porcelain industry.

Figure 8. Single Piece 380 KV Transformer Bushings. Height 16 Feet (before firing).

*Rosenthal and Stemag Information, April 1958

Figure 9. Single Piece 400 KV Cable End Bushing. Height 13 Feet, 39 Inch Diameter (Fired)

With ever increasing voltages and inside pressure application, it is this writers opinion that in the future the American electrical industry will also demand similar large single piece porcelains.

Other glaze-sealing methods.

Another widely employed glaze-joint method consists of sealing pre-shrunk (i.e. glazed, prefired) plugs or diaphragm washers into smaller type apparatus bushing of which an example is shown in Figure 10. The plugs may be formed from pugged blanks or made by the dry-press method. The important factor is that these plugs be made from the same wet process body as others made from a higher feldspar body (G.E. Dry Press Porcelain) caused thermal shock failures due to different expansion between the two bodies. The counte-bore dimension holding the pre-shrunk plug must be closely controlled and the prefired plug gauged for diameter dimensions in order to obtain a close fit and air-tight seal. A glaze free from blistering (G.E. 21F) is used for these insert plugs.

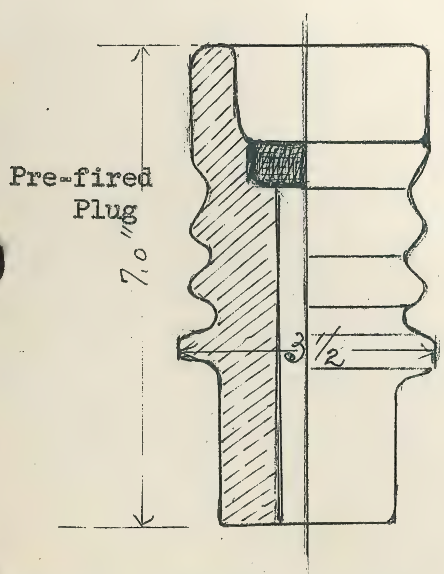


Fig. 10. Bushing with glaze-sealed porcelain plug.

Chapter XI. Drying Methods

In the mixing of porcelain bodies large quantities of good city water or de-mineralized (purified) industrial water is used. This water must later again be removed, during the various manufacturing stages by drying the finished ware before it can be glazed and put in the kilns.

Drying Process

Drying is then simply the elimination of moisture (by evaporation) from the ceramic body. As an example, suspension and pintype insulators are hot-pressed with 19 percent moisture in the plastic body. By placing these insulators, while still in the plaster molds, in steam heated "mold release" dryers, or moving them by conveyors under fast moving fans at room temperatures, from 2 to 3 percent of the moisture is removed and the insulators become firm enough to be lifted from the molds and to be "green finished" to final shape. With these operations completed the final drying, i.e. the elimination of the remaining 15-16 percent moisture takes place in steam heated, tunnel truck humidity dryers. The insulators are then ready for glazing and kiln firing.

A mold release, mangle-type, dryer for pintype insulators is shown in photograph, Figure 1.

Mold Release

Drier

Figure 1. "Hurricane" - Philadelphia Drying Machine Co. Dryer with automatic contineous shelf conveyors. Drying temperature - 110-125°F, mold release in 45-50 minutes. 5000 to 6000 pintype insulators can be conditioned for mold release per daily shift.

The theory of drying ceramic ware has been covered in recent years in extensive and informative publications by ceramic technologists and dryer manufacturers. It is, therefore, considered beyond the scope of this chapter to go into the detail of this science.

However, a short discussion of applied drying practices and experiences in this important step of insulator manufacture is deemed advisable and is presented here.

Fundamentals of Drying

All elements affecting drying - temperatures, air circulation and humidity - must be controlled. Green finished insulators, pugmill blanks, or only partially dried, i.e. still moist ware when placed in dryers, must be dried from the inside out to avoid drying cracks. In order to prevent such defects, the ware is exposed in the first stages of drying to a high humidity, so that the capillaries or pores in the body remain long enough open for the inside moisture to escape. A high velocity air is also circulated around the ware to carry the released moisture away. With the use of modern control instruments available and drying schedules carefully worked out and adhered to by plant operators, the drying of the various insulator shapes is now accomplished in 24 to 68 hours today instead of many days and weeks in former years. A considerable saving of floor space has also resulted from today's faster drying cycles.

A practical approach to the drying problem has been the segregation of those items which are difficult to dry without cracking. Extra large pieces and such with heavy walls are dried in humidity controlled batch dryers after several days of floor drying. Sometimes, protective canvas hoods were used to protect certain sections against the drafts of the air circulation fans. Unevenly dried thick wall pugmill blanks invite drying cracks during or shortly after turning. A moisture check on the blanks will show whether or not the blanks are dry enough to be turned.

The practical problems of drying then are to create and control the conditions necessary for the most efficient drying cycle, and to coordinate them with methods and flow of production and economy of operation.

This has been accomplished after thorough engineering studies in the case of suspension insulators which are dried in the dryer shown in Figure 2.

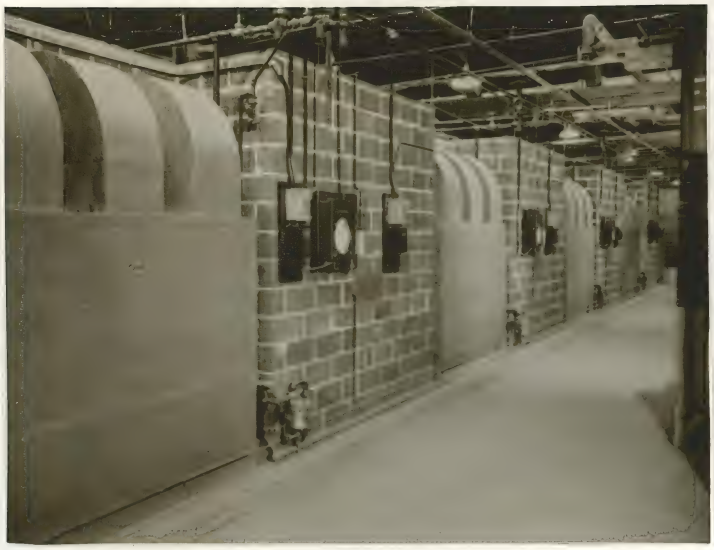
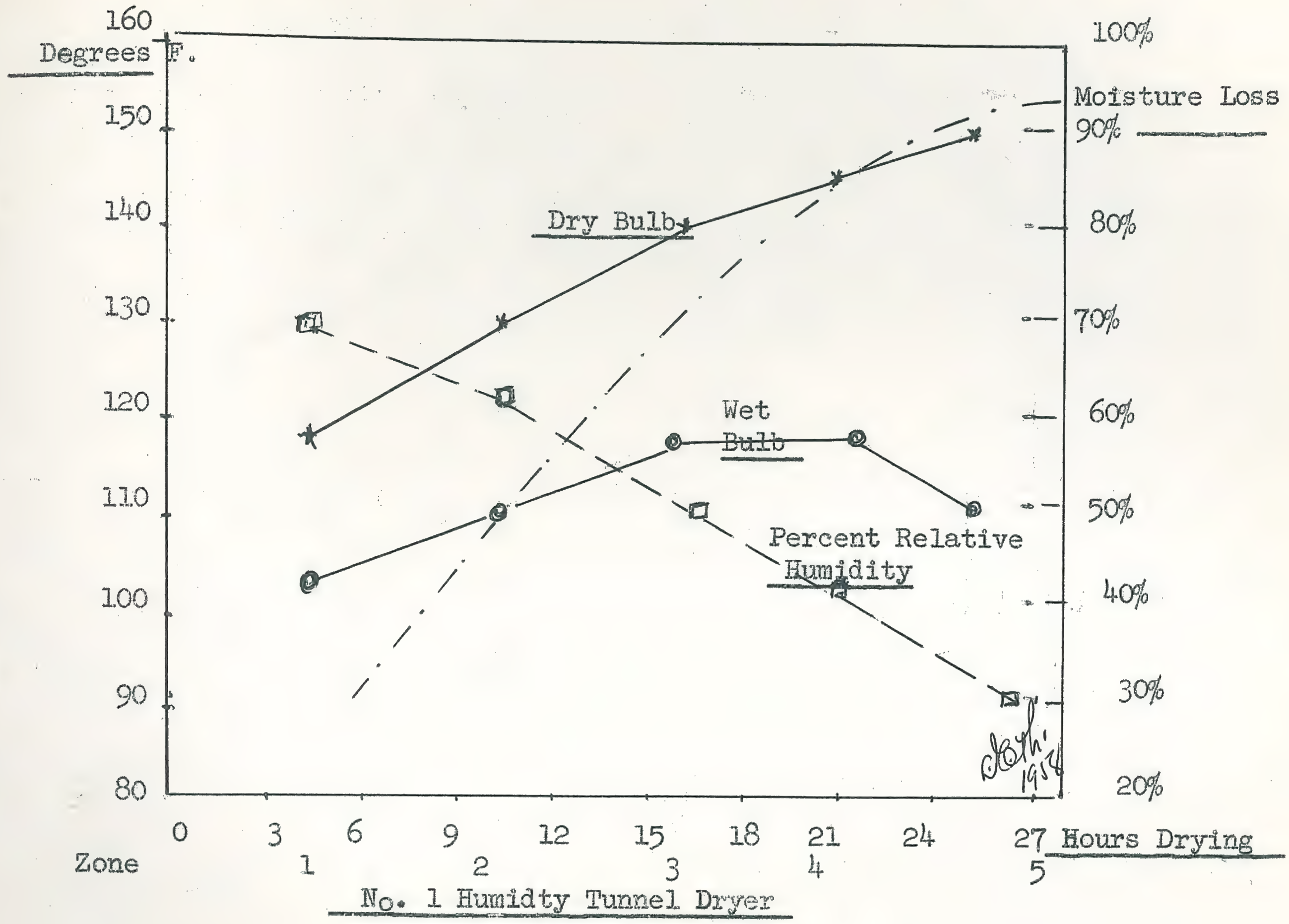


Figure 2. No. 1 Dryer (100 ft. long, 5 controlled zones, carrier units, 3 tracks-18 cars each). Time per track 1 hour 30 minutes.

In Photograph, Figure 3 loaded mono-rail cars with "green finished" suspension insulators entering the dryer.

Figure 3. Dryer No. 1. The shelves are perforated to allow moisture to escape from the inside of the insulator head.

Diagram, Figure 4 shows the atmospheric conditions, dry and wet bulb temperatures and percent humidity, maintained in the five zones in dryer No. 1 for suspension insulators.



As an illustration of the magnitude of the water removal called "drying", more than two (2) tons of water is removed from the 4000 insulators in the dryer during the 27 hour cycle.

The proper placing of the insulators on dryer cars is another important factor in the rate and efficiency of drying. The essential point here is to provide plenty of uniform air circulation below, above and around the ware to be dried. An illustration of good drying practice is given in Photograph, Figure 5.

Figure 5. Schenectady Proctor Dryer Car with Ware. Note insulators placed on elevated boards with holes in center to allow hot air circulation.

<u>Infra-Red Drying</u>

Steam heat is employed in all Baltimore dryers. Two insulator manufacturers, Illinois Porcelain and Victor Insulator Company, employ infra-red (lamp) dryers for mold-release of hot plunged line insulators.

Infra-red drying has become an acceptable practice in the pottery industry, confined to thin shapes of a limited thickness, but it has been found that infra-red (radiant) drying is not practical for complicated pieces and section above one inch thickness.

Figure 6. Victor Infra-Red Lamp Conveyor
Type Tunnel Dryer

At Illinois Porcelain Company a second infra-red dryer is used for drying plaster molds on their return trip to the hot presses. It is reported that this is a tunnel dryer heated by glow-bar heating units.

Experimental drying of jiggered shells for multi-part post type insulators at Baltimore in 1948 with 250 watt lamps did not only prove unsuccessful but also expensive. Some sections exposed nearest to the source of radiant heat for over two hours were too dry, the other section, away from the heat, too soft for "green finish". Infra-red heating lamps focus a high concentration of energy upon the ware, creating hot spots and drying strains (even cracks) in the pieces. This method of heating can also be very destructive to plaster molds which, when exposed to temperatures of 160°F for more than 30 minutes, will crack and disintegrate. Perhaps a dryer system, combining infra-red radiation with controlled air circulation, may have a better future in successful drying of various insulator shapes.

<u>Gas Heated Conveyor</u>

<u>Tunnel Dryer</u>

The Porcelain Products Company at Parkersburg employs a dual conveyor type, gas heated (Dravo Counter Flow) dryer for mold release and mold drying.

The plunged insulators, while still in the molds, travel in one direction to a "green finishing" station, while the empty molds are returned in another parallel compartment in an opposite direction to the hot press. The dryer uses high velocity air heated to 200°F. From all information available this drying system has proved quite successful, operating with several daily turnovers of the molds.

In concluding this chapter on the important subject of drying, a few other, less orthodox drying methods will be shortly discussed.

1. Vacuum Drying

Vacuum Drying

Drying methods, employing reduced pressure and heat are used widely in the food and chemical industries. In 1954 ceramic engineers at Baltimore experimented in this by placing some hot plunged suspension insulators in bell jars, which were evacuated with 28" or less vacuum applied; evaporation took place fast at first, then, with the pieces cooling rapidly and with a consequent drop in vapor pressure, the drying slowed down fast. Even with heat supplied, vacuum drying of such ware proved both, impractical and uneconomical.

2. High Frequency (Dielectric Heating) widely used today in baking foundry sand cores, has been tried to dry pugged blanks. The principle of high frequency is to generate the heat inside the clay article. For this purpose freshly pugged cylinders of various diameters were covered with metal plates or electrodes which were connected to the source of HF power. Dielectric losses within the wet body create heat throughout the material. It was found that the blanks developed surface cracks. Switch shell insulators in molds were also dried in a commercial tunnel drier, but they also developed cracks and case hardening and the plaster mold disintegrated due to the fact that the heat could not be controlled.

High Frequency

(Dielectric Heating Clay Ware)

3. Induction Heating

Mold Release by Induction Heating

Since clay bodies and plaster molds are not good conductors of electricity, induction heating cannot be employed for mold release. However, by coating the inside of ceramic (permanent) molds with a conducting (metallic) layer, and applying induction currents(from a G.E. 5 K.W. oscillator), the insulator heated up fast enough on the surface so that within a few minutes they could be lifted from the mold for further stiffening up by air and "green finishing". It is visualized that in the future, porous metal molds, for instance light weight aluminum molds, may present a possibility for hot plunging and fast release of insulators by induction heating in a conveyorized arrangement.

The drying period of a plastic porcelain body may be shortened and the drying achieved more safely by the addition of flocculating chemicals (NaCl, Acetic Acid, Aluminum Chloride, etc.) to the body slip. These compounds coagulate the clay particles into aggregates and thereby produce capillaries resulting in an easier diffusion of the internal moisture to the surface. Advantage of this has been taken by the addition of small amounts of aluminum chloride to the G.E. 740 plastic body. In addition to faster filterpressing, this has also proved a factor in the safer, crack-free ware drying of the Baltimore body today.

<u>Effect of Chemical Treatment on Drying Rate</u>

Glazes - Nature and Functions

Porcelain glazes are considered glasses belonging to the large chemical family of alkali-lime-silicate compositions, but so adjusted to meet the requirements for coating ceramic bodies with a continuous, smooth and self-cleaning surface.

Other functions of glazes or glaze-like surface coatings consist of surpressing radio interference or to overcome high voltage stress concentration on apparatus porcelains.

From a ceramic-chemical viewpoint, glazes, like glasses, are the reaction products of acidic, basic, and to a certain extent of coloring metallic oxides. Expressed in more common and practical terms, insulator glazes are fusible mixtures of feldspar, clay, lime and flint, i.e. composed of identical basic raw materials used in body compositions.

Since electrical porcelain is a one-fire product, glaze and body must mature under the same firing conditions.

Considering the fact that glazing insulators represents the last manufacturing operation before firing, the preparation and application of glazes must receive utmost attention and care if high losses of fired ware is to be avoided.

The earliest insulator glazes were "slip glazes" adopted from other branches (stoneware) of the ceramic industry. Slip clays from Albany (N.Y.) and Rowley (Michigan) deposits were simply ball milled with sufficient water and the insulators dipped in the suspension. Years ago, the author obtained chemical analyses of those extremely fine grained clays which showed the following compositions:

	Albany Slip Clay	Michigan Slip Clay
Silica and Alumina	70.0%	54.0%
Iron Oxide (Fe_2O_3)	5.8	3.8
Lime (CaO)	5.7	11.6
Magnesia (MgO)	2.5	4.2
Potash and Soda (KNa_2O)	5.7	7.1

The fired color of these slip glazes varied from a yellowish-brown to mahogany, but under the slightest reducing kiln atmosphere, turned to a black, often metallic luster. The

yellowish-brown or mahogany-brown glaze became and is still the standard color on American line insulators.

With ever increasing demands for a more stable mahogany color, insulator manufacturers began to develop synthetic Albany slip glazes, usually high in feldspar and low in silica to obtain the high gloss and smoothness and low thermal expansion of the Albany slip. Such glazes, however, proved to be much inferior in mechanical strength. Today, slip glaze is not used anymore in electrical porcelain glazes.

Research on Stresses in Glazes

Considerable research on glaze stresses here and abroad showed that the coefficient of thermal expansion of a glaze has the most important effect upon the mechanical strength of the fired body. Our own extensive research activities at Schenectady and Baltimore Ceramic Laboratories discovered that glazes with a thermal expansion lower than the body, would increase the strength as much as 40 percent, whereas glazes with only slightly higher thermal expansion would lower the strength of the porcelain as much as 60 percent. Glazes that developed crazing would almost completely destroy the strength of the porcelain. This development and others later to follow, which became know as Locke Controlled "Compression" Glazes, have now been adopted by every other American and Canadian insulator manufacturer.

Effect of Composition on Glaze Fit

In 1936 the author published a first research paper [1] on the effects of glaze composition and thermal expansion upon the mechanical strength of electrical porcelain. The results showed that glazes high in feldspar and lime produced high expansion and low mechanical strength; whereas a high flint, and to a certain extent, clay content, increased the mechanical strength of the porcelain body to which such glazes were applied.

(1) Journal American Ceramic Society, March 1936.

Some of the results are plotted on a curve shown in Diagram, Figure 1.

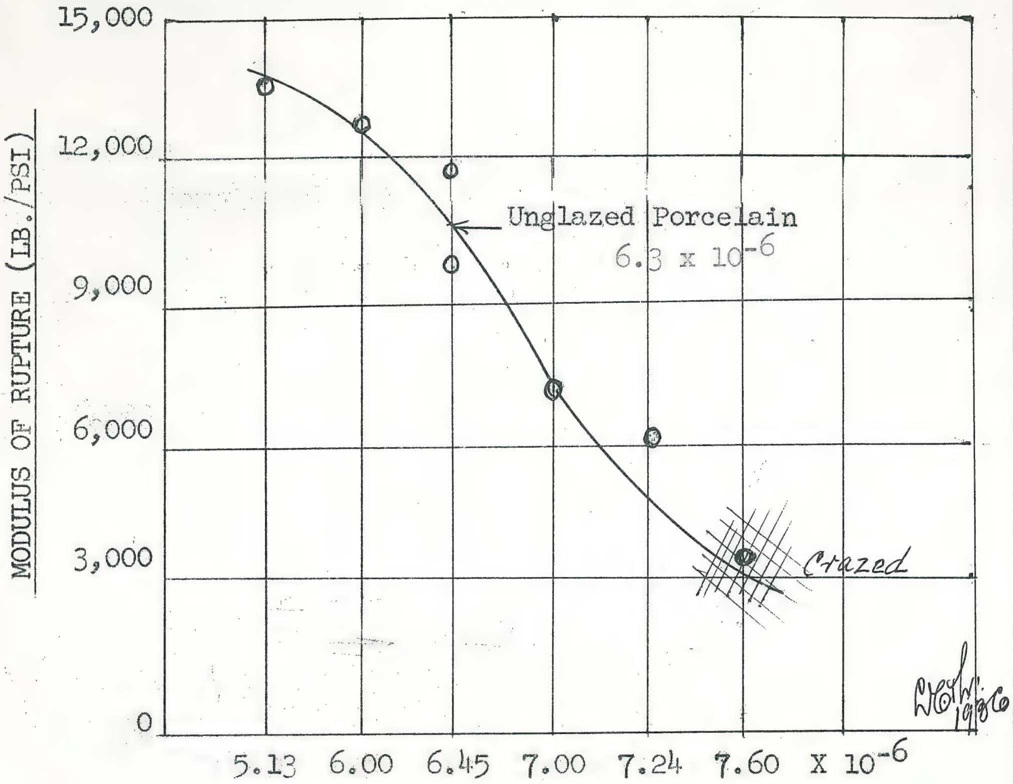


Figure 1. Calculated Coefficient of Thermal Expansion 20-550°C

Similar results were reported several years later by a British insulator manufacturer by presenting data which is in substantial agreement with that of the author. The British publication shows that by glazing an electrical porcelain body (thermal expansion 5.83×10^{-6}) with a glaze having an expansion of 5.43×10^{-6}, an increase of 33% in mechanical strength was obtained. However, using a glaze with a higher expansion coefficient (6.13×10^{-6}) the strength of the flexural strength was reduced to 15% below that of the unglazed porcelain body.

What is a "Compression Glaze"?

It would be fair now to raise the following questions:" How does a high strength compression glaze develop in firing and how is it possible to tell whether a glaze is actually in compression or tension?"

How Does Glaze Stresses Develop?

The answer to the first part of the question is that a glaze with a higher coefficient of expansion will try to shrink more in cooling than the body will allow and in so doing will put itself under a high tensional stress.

Conversely, if the glaze has a lower coefficient of expansion, the porcelain tends to shrink more in cooling. But as the thin glaze must come along with the great mass of porcelain so that, at ordinary temperature, the glaze has been pushed together and is, therefore, under compression.

As to the second part of the above question, there are several ways of measuring stresses in glazes. Three principal test methods used by ceramic engineers will be described as follows:

Methods of Measuring Glaze Stresses

a. The coefficient of thermal expansion may be calculated by multiplying the percentage of the glaze-forming oxides with factors established by F. Hall (Jour.Am.Ceramic Soc.). The thermal expansion values shown for experimental glazes in diagram Figure 1 have been computed by using these factors. The difference between the expansion of the glaze and that of of the body at the softening of glaze is taken to be a measure of the final stress in the glaze. If it is positive, the glaze is in tension, and if it is negative, the glaze is in compression.

   It is realized that such calculated thermal expansion values are not necessarily true but rather comparatively ones for reason that glazes tend to undergo changes in composition at the glaze-body contact. This fact, however, does not detract from their usefulness.

B. The thermal expansion of bodies and glazes may be determined separately by means of a dilatometer or interferometer while heated and cooled in the furnace. By this method, Locke bodies and glazes have been tested with the results plotted on a diagram as shown in Figure 2 (page 125).

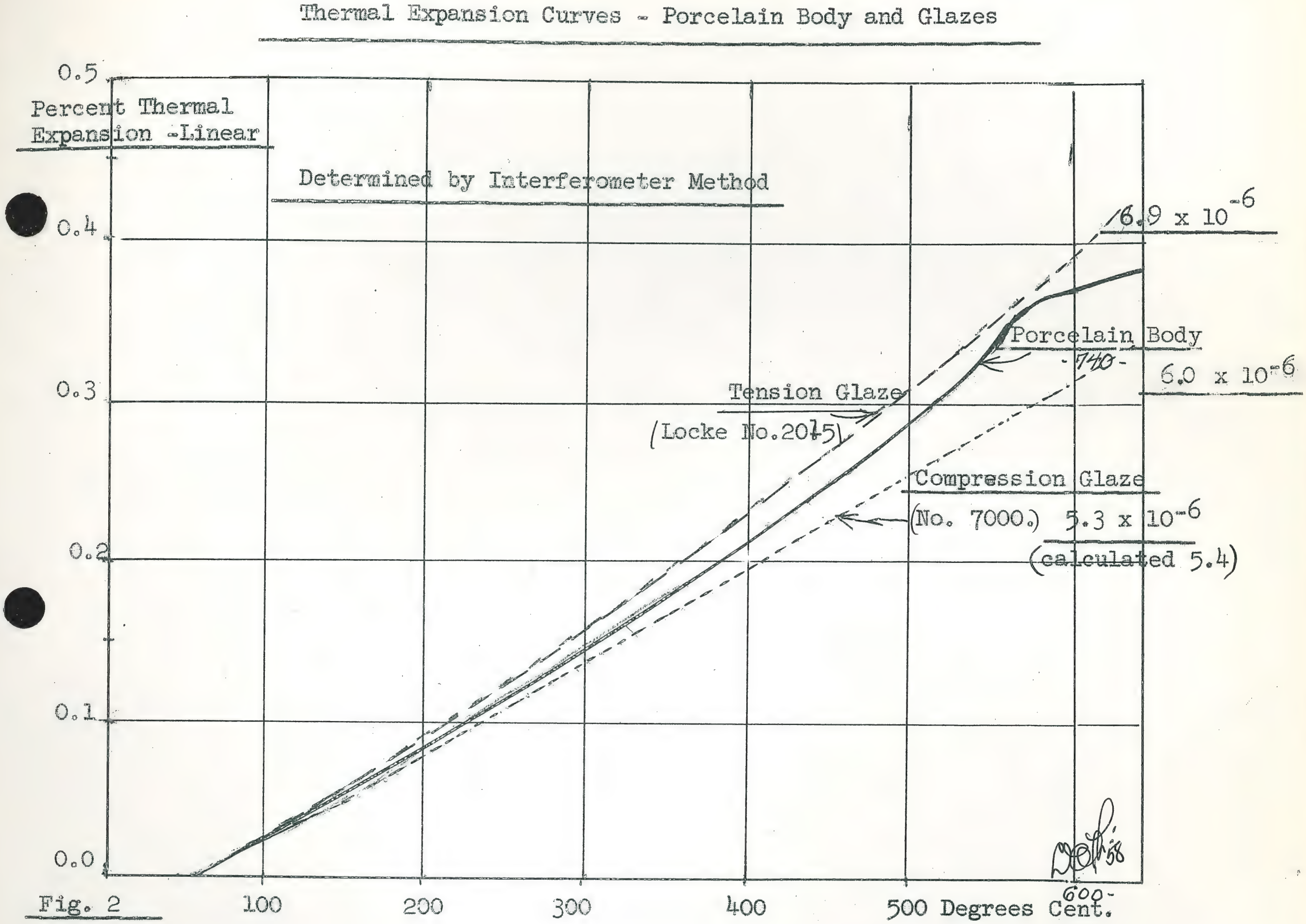


Fig. 2

Such interferometer measurements were made in 1948 of bodies and glazes from sections of insulators manufactured by G. E. competitors. The resulting thermal expansion values are presented in Table, Figure 3.

Figure 3. Coefficient of Thermal Expansion Data (1948) by Interferometer Method (20°C to 550°C)*.

Manufacturer	Body	Glaze	Difference (Less Than Body)
Locke No. 740	6.5	5.3×10^{-6}	17.0%
Lapp Company	7.0	5.8×10^{-6}	17.2%
J.-D. Company	6.6	5.4×10^{-6}	18.2%
Thomas Sons Co.	7.1	6.0×10^{-6}	15.1%
Pinco Company	7.4	6.4×10^{-6}	13.5%
Victor Insulator	6.2	5.5×10^{-6}	11.3%

C. The most practical method of measuring glaze stresses in the so-called "Ring Test" which has now been adopted by many porcelain manufacturers, including Ohio Brass Co. and Westinghouse. In this test glazed porcelain rings 1-3/4 O.D, 1-1/4 I.D. and 3/4" long are first marked with reference points and the distance in millimeters measured on a Brinell Measuring Microscope, such as shown in Photograph, Figure 3.

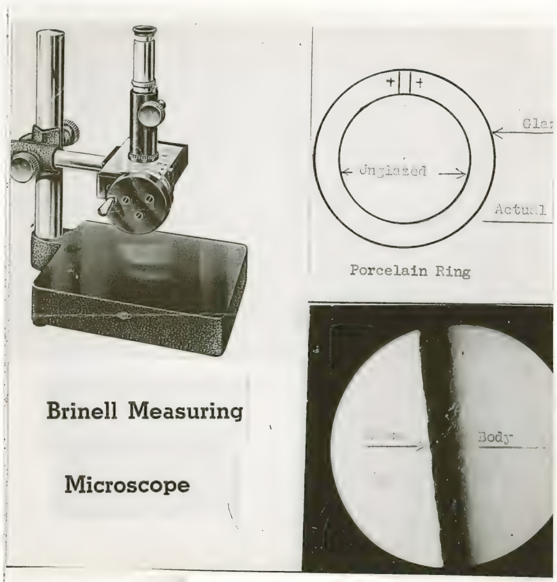
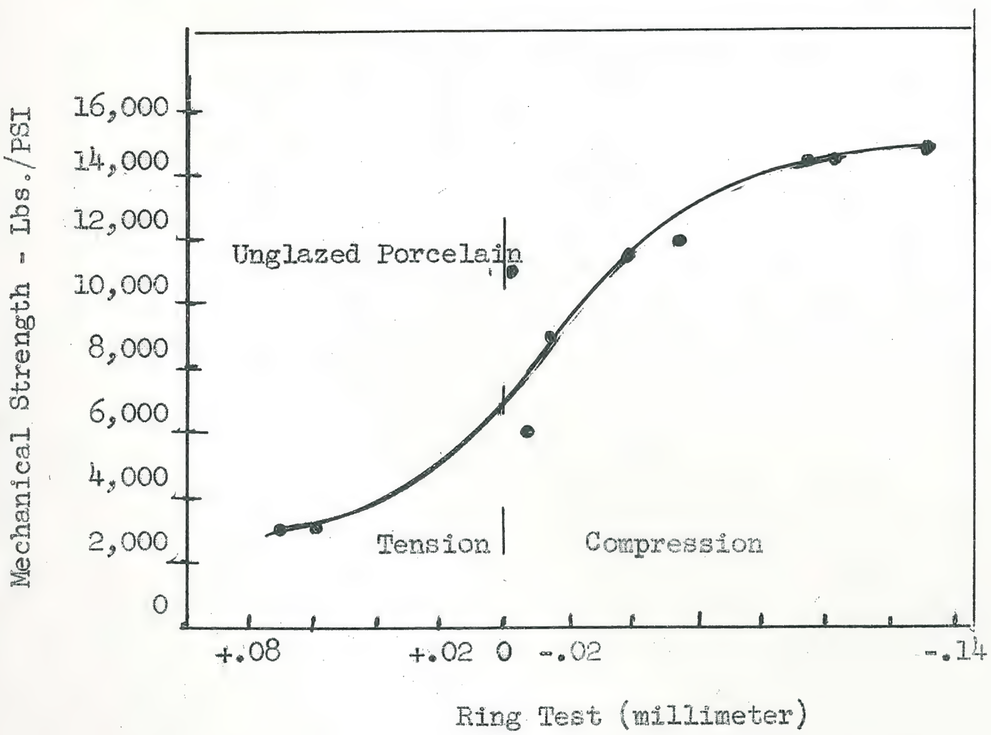


Figure 3. Porcelain Ring and Microscope for Measuring Glaze Fit

*This is the average softening point of the glazes. Such separate expansion measurements on bodies and glazes likewise do not take interfacial composition changes in the glaze into consideration. The results are nevertheless useful. The above tabulated measurements indicate that these insulator manufacturers now also use compression type glazes on their ware.

The rings are then cut on a diamond wheel between the reference points and the distance again measured. If the glaze is in compression, the ring will close in, if the glaze is in tension, the ring will open up and the distance increased between the reference points.

The expansion and contraction data presented in Figure 4 has been obtained from a series of experimental glazes of various compositions. The flexural strength was obtained from testing porcelain cylinders glazed with the same experimental glaze compositions.



Test Ring Glazed on Outside Only

It has been known for sometime that the thickness of glaze application has considerable influence on glaze fit. Even a compression glaze, if applied too heavy, will appreciably lower the mechanical strength and thermal shock resistance of the porcelain.

Research conducted by Baltimore ceramic engineers in recent years has produced more fundamental information on the subject of glaze application. Data obtained on glaze thickness versus mechanical (flexural and impact strength) both on test rods and on suspension insulators are shown in diagrams Figure 5 and Figure 6.

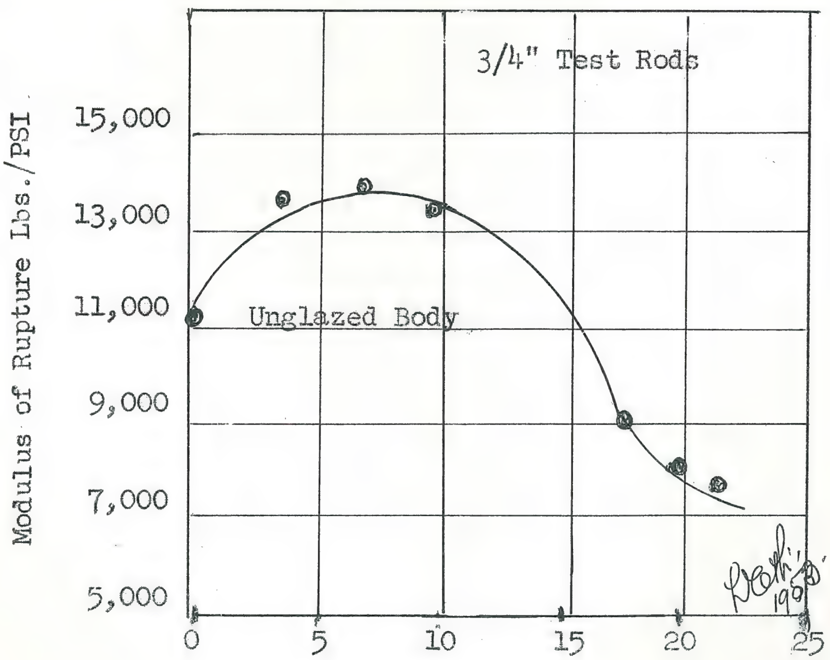


Figure 5. Glaze Thickness (mils)
No. 7000 Glaze

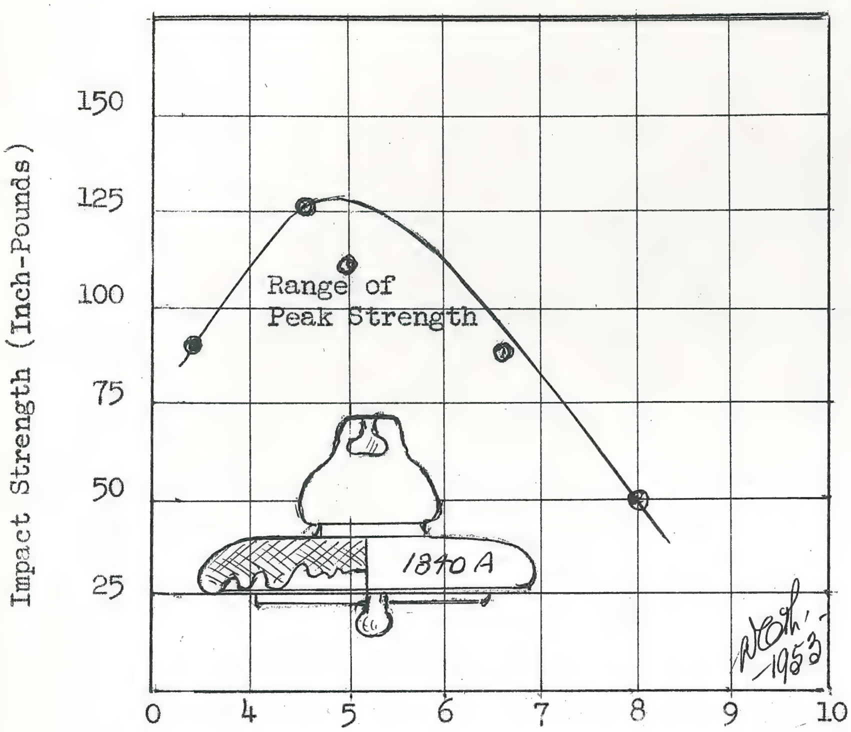


Figure 6. Glaze Thickness (mils)

Peak stretch was obtained with a fired glaze thickness of the order of 4.5 to 5.5 mils. The strength of the porcelain then dropped sharply with increased thickness of the glaze layers.

In order to maintain such close limits a control of the glaze thickness before firing is essential.

A sample dial instrument, such as shown in photograph, Figure 7 is used for measuring the thickness of the unfired glaze. By taking the measurements on the glaze first and then on the bare body, the thickness of the glaze may be calculated.

Figure 7. Dial Instrument for Glaze
Thickness Control

Manufacturing specifications at Baltimore require an unfired glaze thickness of the order of 8 to 10 mills for the No. 7000 mahogany and 9.5-11.0 for the No. 2007 chocolate glaze.

The thickness of the fired glazes may also be checked by cutting thin sections from fired insulators and examine these sections on the same Brinnell microscope, shown in photograph, Figure 4.

Up to about ten years ago very little information was available on the microstructure of insulator glazes.

Microstructure of Insulator Glazes

Microscopic studies carried on in our ceramic labrotories on thin glaze sections chipped from fired insulators showed that many glazes contained undissolved material (quartz or coloring oxides) while others contained a large amount of gas bubbles. Some materials, such as zircon opacifiers are desirable, others like large quartz or metallic oxide crystals, are undesirable.

Great activity in firing porcelain glazes prevails at the body-glaze contact. As a result of this inter-action some of the body material, especially alumina, is dissolved and re-crystallization takes place in the form of interlocked mullite needles.

This development produces some kind of a cushion or buffer which not only locks the glaze tightly to the body, but also greatly increases the fired strength and thermal shock resistance of the glazed porcelain. This crystallized interface is illustrated in photograph, Figure 8.

No. 7000 Glaze

Interface

Porcelain Body

Figure 8. Photomicrograph No. 7000 Glaze on No. 740-1 Porcelain. 500X Polarized Light.

Glaze Preparation and Control

Glazes are prepared by grinding the ingredients with water in ball mills, using 2 inch diameter flint pebbles as grinding medium.

The desired degree of fineness is obtained by controlling the grinding time, i.e. the speed and total number of revolutions per mill. Glazes containing hard-fired color stains and frits must be ground longer than the so-called raw glazes. The average grain size of the No. 7000 glaze slip is about 4 to 5 microns, with a zero amount on the 325 mesh screen (44 micron) and 25% on the 1 micron particle size. Actual tests made by Baltimore Ceramic Laboratories show that the strength of glazed test rods was 30% higher for the No. 2007 chocolate glaze ground 36 hours than for the same glaze ground only 8 hours. A better appearance and smoothness was also obtained from the 36 hours grinding. Over-grinding, however, must be avoided as it tends to cause crawling in firing or settling out of the glaze slip.

Effect of Fineness

Figure 9. Schenectady Glaze Mills, Screening Equipment and Storage

Specific gravity and viscosity requirements vary with different glaze slips, depending upon the method of application, i.e. spraying or dipping. These properties must be closely controlled in order to obtain the required glaze thickness. Manufacturing specifications cover in detail this phase of work.

Glaze-Slip Adjustments

Flocculants (calcium hydroxide, etc.) or deflocculants (sodium silicate, etc.) may be added to adjust the consistency of the glazes, but they should be used carefully and sparingly. These chemicals have the tendency to migrate and accumulate on the edges of insulator skirts during drying and, if used in excess, will cause blistering and rough edges in firing with a total loss of the ware.

Hand-dipping of line insulators was the standard method of glaze application for more than 40 years. Some smaller apparatus bushings are still glazed by hand-dipping.

Cast insulators, such as cut-out boxes and leading-in bushings (goose-necks) were also formerly glazed by dipping. Spraying this ware in recent years has completely eliminated pinholes in the glaze, one trouble which has beset this industry for years.

Today, practically every insulator manufacturer has some semi-automatic or fully automatic glazing machines. This has not only resulted in labor saving (elimination of dipping pieces in water before glazing) but also in greater uniformity of glaze thickness and color of the insulators.

The automatic glazing machine (G.E. patent) illustrated in photograph, Figure 10, preforms a number of operations formerly done

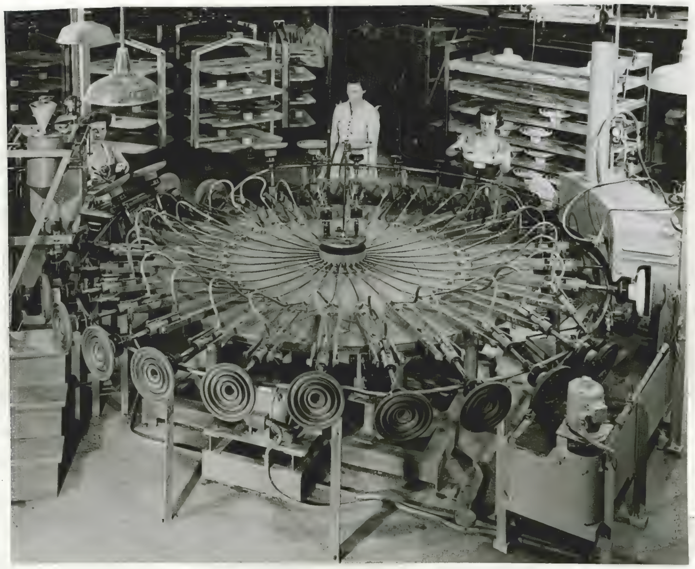


Figure 10. Glazing 10 Inch Suspension Insulators at 3.6 RPM - 3200 Pieces are Glazed Per Shift

by hand. At the first station at the right, the dust is blown off and a light water spray applied to the insulators. Then, traveling on a rail, the insulators are rotated in the liquid glaze, carefully controlled for specific gravity and viscosity, everything is timed and so arranged that the glazed insulator is dry enough to receive a coat of binder-containing glaze and sand belt. This machine, the most complete and efficient that can be found in any insulator plant today, has eliminated all variables of former human operation.

Another, similar machine automatically glazes pintype insulators by first dipping them into a semi-conducting (meta) glaze and then immediately in the regular chocolate glaze. Revolving at 3 RPM - 5800 pintype insulators can be glazed on this machine per shift. The use of special (G.E. patented) new semi-conducting glaze of carefully controlled consistency and width of the applied glaze band are the outstanding features of this method of glazing pintype insulators.

Automatic Spray-Glazing Apparatus Porcelains

Photograph, Figure 11, shows an automatic, multiple spindle conveyor glaze spraying machine for a variety of apparatus porcelains which also formerly sprayed by hand operation.

Figure 11. Binks Continuous Glaze - Spray Machine Using 45 Spindles, As Shown in Photo, 580 Bushings Per Hour are Glazed on this Machine.

This machine, utilizing a pre-set spray pattern locked for control and uniformity, is capable of a high output with handling limited to load, unload and inspect the sprayed insulators.

The glaze slip consistency and air pressure must be controlled to obtain a uniform glaze coating on the insulators.

Larger bushings are glazed by hand spraying, either on a lathe or on a turntable completely enclosed in a dust collector booth. Several coats are applied in succession to obtain the proper thickness, which should be in the order of 10-12 mils. Experienced operators are required for such glazing jobs, as there are variables in the drying behavior of the softer, more open casting body and the much denser plastic body. The former absorbs the glaze much faster, whereas with the plastic body the spray gun must be held at such a distance that the wet glaze will not run and form a wavy coating.

Photograph, Figure 12, shows a porcelain bushing being sprayed with No. 21F glaze.

Figure 12

Here also a dial gauge can be used to check the glaze thickness on the insulator.

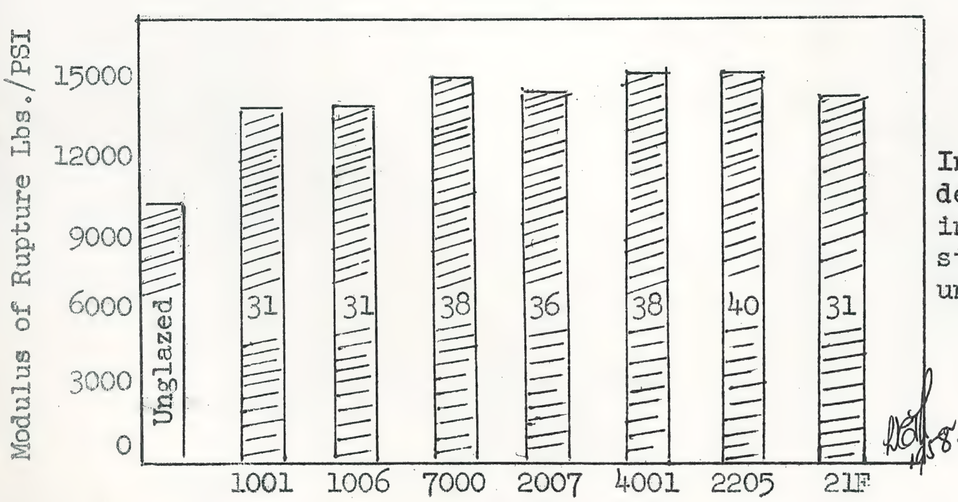
Colored glazes are obtained by the addition of metallic oxides, such as cobalt for blue, chromium for green, red iron and manganese for brown.

Chromium oxide is subject to vaporization in firing and raw glazes containing iron oxide, such as the Locke No. 7000 mahogany glaze, will turn darker to almost a chocolate shade by the reaction with such chromium vapor. For this reason, suspension and fog type insulators are usually fired in a separate kiln from that of chocolate glazed apparatus bushings and pin type insulators. The No. 21F mahogany glaze, containing a prefired brown stain, is not affected by such chromium vapors, and, therefore, can be fired in any of the available kilns.

A large number of porcelain glazes have been in use over the years at the Victor, Baltimore and Schenectady porcelain plants. Some of the older , now obsolete, glaze compositions are shown in Table I (Albany slip glazes).

Progress in the development of improved white, colored and semi-conducting glazes at Baltimore has been rapid in recent years, consisting chiefly in stronger glazes, more uniform in color and more suited to meet changed, i.e. mechanized manufacturing methods.

Tables II, III, IV and V show present standard glazes used at Baltimore and by some other insulator manufacturers. All present Baltimore glazes improve the mechanical strength of the porcelain by 30 to 40%, as shown in diagram Figure 13.



Inserted figures denote percent increase in strength over unglazed porcelain

Fig. 13 - Strength of Standard Glazes

Table I

Albany Slip Glazes - Mahogany and Chocolate Brown

1 Early Locke Glazes 1900 etc.		2 Schenectady No. 21 1946		3 Locke, Victor and Baltimore		4 Westinghouse 1933		5 Westinghouse 1936	
Albany Slip	100%	Albany Clay	75%	Albany Clay	23.00%	Albany Clay	83.0%	Albany Clay	87.5%
Clay - plus		Nepheline Syanite	8	Ball Clay	13.83	Michigan Clay	8.5	Michigan Clay	1.50
later additions		Potash Spar	9	Feldspar	23.00	Whiting	0.0	Feldspar	3.75
of Manganese		Whiting	4	Whiting	14.00	Plaster Mold		Flint	2.25
Dioxide and		G.E. 1075		Flint	18.00	Scrap	5.0	Ferric Oxide	2.50
Whiting to		Insul. Glass	4	Iron Chromate	4.00	Manganese Oxide	3.5	Chrome Oxide	2.50
stabilize			100%	Manganese Oxide	2.25		100.0%		100.0%
color.				Ferric Oxide	0.92				
				Chrome Oxide	1.00				
		#1075 Glass Composition			100.00%				
		SiO_2	34%						
		PbO	30						
		B_2O_3	27						
		Al_2O_3	7						
		Na_2O	2						
			100%						

Remarks:

Glaze No. 1 - This type of glaze was used for many years on all line insulators (yellowish-brown color).
Glaze No. 2 - This was a special glaze for circuit breaker bushings, operating in oil. Superceded in 1945 by No. 21F Glaze.
Glaze No. 3 - Victor and Baltimore chocolate brown glaze - discontinued in 1949.
Glaze No. 4 &
Glaze No. 5 - Westinghouse mahogany and chocolate glazes, discontinued after 1936.

Table II

Present Day Mahogany Glazes - General Electric and other Manufacturers

1		2		3		4		5	
Locke No. 7000		G.E. No. 21F		Westinghouse		Victor		Knox	
Feldspar	17.5%	Feldspar	10%	Feldspar	24.8%	Feldspar	13.00%	Feldspar	19.38%
Whiting	16.3	Nepheline Syenite	10	Whiting	12.4	Whiting	15.20	Whiting	19.90
Ball Clay	13.5	Whiting	16	Talc	6.0	Ball Clay	12.50	Ball Clay	5.52
China Clay	9.7	Ball Clay	19	Ball Clay	20.0	Florida Clay	9.60	China Clay	9.84
Flint	32.0	Pemco Frit #890	4	Flint	28.4	Bentonite	1.00	Bentonite	2.00
Manganese Oxide	6.5	Harshaw Stain N-508	35	Ferric Oxide	4.8	Ferric Oxide	4.25	Ferric Oxide	3.05
Ferric Oxide	4.5	Flint	6	Manganese Oxide	3.3	Manganese Oxide	5.95	Manganese Oxide	2.53
	100.0%		100%	Cobalt Oxide	0.3	Chrome Oxide	1.50	Chrome Oxide	1.28
					100.0%	Flint	37.00	Zinc Oxide	0.50
							100.00%	Flint	36.00
									100.00%

Remarks:

Glaze No. 1 - This is Locke Insulator standard high compression glaze (revised in 1953).
Glaze No. 2 - This is another patented G.E. Glaze (1946). Both the frit and the brown stain are G. E. compositions and these materials are supplied to G.E. specification. Special glaze for bottom part bushings.
Glaze No. 3 - Westinghouse mahogany brown glaze, used on bottom part bushings - oil circuit breakers.
Glaze No. 4 - Victor brown glaze - darker than G.E. No. 7000.
Glaze No. 5 - Knox compression type brown glaze. Knox also has a high feldspar non-compression chocolate glaze, high in feldspar content.

Table III

Chocolate Brown and Brown Joint Glazes

1 Locke No. 2007		2 Locke No. 2015		3 Westinghouse No. 278		4 Lapp		5 Locke #220 Joint Glaze	
Feldspar	18.5%	Feldspar	45.4%	Feldspar	36.3%	Feldspar	22.5%	Feldspar	22.5%
Whiting	19.2	Whiting	17.2	Whiting	11.0	Nepheline Syanite	6.28	Whiting	19.7
Ball Clay	12.3	Ball Clay	10.1	Ball Clay	12.5	Whiting	8.06	Ball Clay	2.6
China Clay	10.3	Flint	17.2	Flint	21.4	Calif. Talc	7.50	China Clay	15.6
No. 7860 Brown Stain	5.0	No. 7860 Brown Stain	10.1	$BaCO_3$	10.0	Ball Clay	16.90	Bentonite	0.5
Ferric Oxide	0.5			Ferric Oxide	3.8	Flint	33.25	Flint	30.1
Flint	34.2			Manganese Oxide	3.0	Chrome Oxide	0.38	No. 7860 Brown Stain	9.0
				Chrome Oxide	2.0	Ferric Oxide	3.94		
						Manganese Oxide	1.19		
	100.0%		100.0%		100.0%		100.00%		100.0%

Remarks:

Glaze No. 1 - Standard chocolate glaze. The 7860 brown stain is a G.E. development now supplied by the Harshaw Co. to G.E. specification. Substitute is DuPont No. 9810. Very uniform color and high strength.

Glaze No. 2 - This high feldspar is no compression glaze. Now abandoned, it was used in hand-dipping cast cut-out boxes to overcome pin holes, etc. Poor heat shock properties (crazing).

Glaze No. 3 - This is the Westinghouse standard chocolate glaze. Lower in strength than Locke 2007.

Glaze No. 4 - This is Lapp chocolate glaze, lighter in shade than No. 2007; not always uniform in shade and gloss when fired in Baltimore kilns.

Glaze No. 5 - Baltimore joint glaze - standard composition.

Table IV

White Glazes - Clear and Opaque

1

Locke 1001
Clear White

Feldspar	23.7%
Whiting	21.3
Ball Clay	10.0
China Clay	11.3
Flint	33.7
	100.0%

2

Locke 1006
Opaque White

Feldspar	35.3%
Whiting	12.8
Ball Clay	5.7
Bentonite	1.0
Zircon Spinel	16.2
Calif. Talc	5.7
Flint	23.3
	100.0%

3

Schenectady 308
Opaque White

Feldspar	27.70%
Whiting	14.3
Zinc Oxide	2.0
N.Y. Talc	3.2
Ball Clay	6.0
Florida Clay	5.6
Flint	28.4
Superpax	12.8
	100.0%

4

Westinghouse
Clear White

Feldspar	35.0%
Whiting	16.0
Ball Clay	16.0
Zinc Oxide	3.0
Flint	30.0
	100.0%

5

Westinghouse
Opaque White

Feldspar	25.5%
Whiting	13.7
Ball Clay	17.7
Barium Carb.	4.5
Magnesium Carb.	2.0
Flint	30.0
Superpax	6.6
	100.0%

Remarks:

Glazes 1 and 4 - These are good clear white glazes, used on apparatus porcelains by G.E. and Westinghouse. The Locke 1001 is the stronger of the two.

Glazes 2, 3 and 5 - These glazes are more like white enamels. They are preferred on dry pressed insulators, as for instance G.E. and Westinghouse vacuum pressed insulators (tap changes, etc.). These opaque glazes are less abrasive due to the zircon (superpax) content and they cover up minute cracks and flaws that are ever present in dry pressed pieces.

Table V

Colored Porcelain Glazes Other Than Brown

Customers often prefer colored glazes for various reasons. For instance, No. 756 dark olive green is used as a protective color for street lighting insulators, light gray to match galvanized or painted hardware or other colors simply for identification purposes. The colored glazes are "production" glazes used at the Baltimore Porcelain Plant.

1 No. 3000 Bright Green		2 No. 756 Dark Olive Green		3 No. 2202 Black		4 No. 5000 Deep Royal Blue		5 No. 2205 Light Gray		6 No. 4001 Slate	
Feldspar	49.7%	Feldspar	13.4%	Feldspar	41.3	Feldspar	19.3%	Feldspar	17.96%	Feldspar	17.39%
Whiting	13.0	Whiting	17.6	Whiting	16.0	Whiting	17.5	Whiting	16.70	Whiting	16.16
White Lead	2.0	Spodumene	5.6	Ball Clay	11.0	Ball Clay	15.6	Ball Clay	13.89	Ball Clay	13.44
Ball Clay	6.7	A-241G Frit	4.8	Manganese Oxide	3.0	China Clay	9.0	China Clay	9.80	China Clay	9.50
Bentonite	2.1	L-128 Green Stain	5.6	Cobalt Oxide	2.5	Flint	33.5	Flint	32.92	Superpax	5.66
Chrome Oxide	2.5	Ball Clay	10.6	Chrome Oxide	1.0	Black Cobalt Oxide	5.1	Superpax	5.73	H-26 Gray Stain	6.00
Flint	24.0	China Clay	7.4	Ferric Oxide	1.0		100.0%	H-26 Gray Stain	3.00	Flint	31.85
	100.0%	Flint	35.0	A-241 Frit	4.0				100.00%		100.00%
			100.0%	Flint	20.2						
					100.0						

Remarks:

Glazes 2, 4, 5 and 6 are compression type glazes. No. 2205 light gray glaze is used also on No. 304 alumina porcelain.

Glazes 1 and 3 have lower mechanical strength and are primarily used on dry pressed insulators.

II. Semi-Conducting Glazes and Coatings

A. Glazes to Suppress Radio Interference

It was shown in the previous chapter that the primary functions of a ceramic glaze is that of producing a smooth, easily cleaned surface covering a completely vitrified article. The only other requirement was that of providing a proper fit between glaze and body in order to obtain a mechanically strong insulator.

This has been the case with electrical porcelain through the years.

The rapid development of radio in the 1920's, however, brought many new problems to producers of electrical equipment, including insulators. Radio interference and noise caused by electro-static discharges on the surface of the metal conductor and the insulator soon became a troublesome problem.

Electrical porcelain manufacturers found a solution in the development of special semi-conducting coatings or glazes applied at critical areas of the insulators, i.e. at the conductor and tie wire. Such coatings, as shown in photograph, Figure 1, were also applied to the pinhole of insulators.

Figure 1. Noise Proof Pintype Insulators

These semi-conducting glazes form an intimate bond between the conductor tie wire or pin and insulator body and, thus eliminate the possibility of brush discharge (corona). These glazes are known as "Meta Glazes" (G.E.) or "Nocorona" by Pinco.

The dull conducting glaze shown on Westinghouse insulators is less desirable than the G.E. 9001-C smooth and glossy glaze. Here, the conducting oxide layer is protected against abrasion, dirt accumulation and deterioration due to weather conditions.

<u>Nature of Conducting</u>

<u>Glazes</u>

Semi-conducting glazes or coatings contain metallic oxides varying from 40 to 90 percent, such as iron, cobalt, titanium, copper and zinc oxides [1] and surface resistivity values have been obtained ranging from 0.50 megohm to several thousand megohms per square.

It appears that, as a general statement, semi-conducting glazes with a surface resistivity from 1 to 20 megohms per square would afford sufficient radio interference protection.

A number of commercial semi-conducting glazes and their ceramic compositions are presented in Table, Figure 2.

One of the most interesting features of these glazes or coatings is that, although the semi-conducting metallic oxides are incorporated in an insulating glassy matrix, they may have conducting properties almost in the same order as those associated with the metallic oxides alone. It has been suggested that the mixture of oxides form an independent continuous crystalline conducting network in the glassy matrix. This theory is supported by photomicrographic evidence, which indicates that the surface of the glaze is not homogeneous.

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(1) Westinghouse Patent 1,987,683 (1935)
R. Thomas & Sons Patent 2,154,387 (1939)
P. H. Sanborn Patent 2,590,893 (1952)
G. E. Patent 2,797,175 (1957)

Table I.

Semi-Conducting Glazes and Coatings

General Electric - Baltimore				Westinghouse				
No. 9001*	No. 9002*	No. 9001-C	No. 200116F	R2555	R281	Thomas Sons	Ohio Brass	Porcelain Products
20%		11.1%	6.10%					8.62%
			4.35					
	2.18%			2.0%	2.0%			
						60.8%	Feldspar	
		14.3	7.90				Flint	23.48%
		12.7	7.30				Whiting	12.13
		11.9	14.35				by difference	36.67
20							55.40%	
15								
			4.50					
16								
	97.82	43.8	43.50	78.4	93.1	19.6	23.45	16.50
		3.0					0.46	
		3.2		19.6	4.9			1.88
2								
						19.6		
			12.00				20.7	0.72
25								
2								
100%	100.00%	100.0%	100.00%	100.0%	100%	100.0%	100.0%	100.0%
0.73-1.8	1.56 with 2009 glaze	9.2, 0.58 with 2007 glaze	3.8-6.7	unknown	unknown	unknown	unknown	2.5

zes became obsolete in 1953.
-C) was substituted for these
omposition of the Ohio Brass
n the chemical analysis of a
t visit. The Porcelain Product
ne of three given in P. Sanborn's

Table I.

Semi-Conducting Glazes and Coatings

	General Electric - Baltimore				Westinghouse			
	No. 9001*	No. 9002*	No. 9001-C	No. 200116F	R2555	R281	Thomas Sons	Ohic
Ball Clay	20%		11.1%	6.10%				
China Clay				4.35				
Bentonite		2.18%			2.0%	2.0%		
Albany Slip Clay							60.8%	Fel
Feldspar			14.3	7.90				Fli
Whiting			12.7	7.30				Whi
Flint			11.9	14.35				by
Copper Oxide	20							5
Nickel Oxide	15							
Cobalt Oxide				4.50				
Manganese Dioxide	16							
Ferric Oxide		97.82	43.8	43.50	78.4	93.1	19.6	2
Chromium Oxide			3.0					
Titanium Oxide			3.2		19.6	4.9		
Strontium Carbonate	2							
Sodium Tungstate							19.6	
Zinc Oxide				12.00				2
Aluminum Hydrate	25							
Barium Carbonate	2							
Total	100%	100.00%	100.0%	100.00%	100.0%	100%	100.0%	1C
Surface Resistivity megohms/square	0.73-1.8	1.56 with 2009 glaze	9.2, 0.58 with 2007 glaze	3.8-6.7	unknown	unknown	unknown	ur

*The 9001 and 9002 glazes became obsolete in 1953. One single glaze (9001-C) was substituted for these in August 1953. The composition of the Ohio Brass glaze was obtained from the chemical analysis of a raw sample from a plant visit. The Porcelain Product glaze composition is one of three given in P. Sanborn's patent.

Photograph, Figure 3, for instance, shows a thin section cut from a pintype insulator, first coated with the No. 9001-C meta glaze, over which the No. 2007 silicate was applied. The resistivity of the 9001-C glaze alone is 9.2 meg./square, with the 2007 cover glaze the resistivity is lowered to 0.58 meg./per square.

Figure 3. Photomicrograph 450X, polarized light. The dark, solid black layer ar the body contact is the 9001-C meta glaze. The outer layer is the 2007 silicate glaze containing a prefired iron-chromium (brown) color stain.

Conductivity Through Mixed Metallic Oxide Crystals

The conductivity in such glazes is thought to be due to mixed crystals, in this case $Fe_3O_4 \cdot Cr_2O_3$ spinels. These spinel patterns were found from X-ray studies at the G. E. Research Laboratory. Crystalline material, such as artificial hematite (Fe_2O_3) and illemanite ($FeO \cdot TiO_2$) in solid solution was found by X-ray analysis in the new 9001-C meta glaze.

Glaze Application

For many years and until 1953 the Insulator Department used two meta glazes, namely the No. 9001 in the pinhole and the No. 9002 on the outside of insulators with the No. 2009 chocolate glaze as cover glaze. The composition of these meta glazes is shown in Table I. Both of these glazes gave trouble of blistering and a rough surface in firing, so that a new, single glaze was developed (No. 9001-C) which has since given satisfactory results.

As shown in Photograph, Figure 4, noise-proof pin-type insulators are glazed on an automatic machine by first dip-coating the controlled area of the head with the No. 9001-C meta glaze and then the entire insulator in the No. 2007 silicate glaze. The pinhole is sprayed with meta glaze on another semi-automatic machine.

Figure 4. Automatic Glazing Machine
Pintype Insulators

The thickness of the semi-conducting glaze is very important and must be held between 3-4 mils before and 1.5-2.5 mils after firing, because the mechanical strength of the glazed porcelain is considerably reduced with increased thickness.

Thickness Control Essential

The thickness of the meta glaze also has an effect upon the resistivity, decreasing sharply to undersirable values beyond 3 mils fired thickness.

(B.) Semi-Conducting Coatings for Apparatus Porcelains (Ceramic Rescons)

Semi-conducting glazes or coatings have become of interest also for distribution of electrical stresses and to eliminate corona on apparatus porcelain bushings.

In 1936 the Schenectady and Baltimore Porcelain Plants supplied some large type porcelain spools with a semi-conducting shield consisting of a copper oxide coating. After firing, this black copper oxide coating was reduced by a chemical treatment [1] to metallic copper to which conductors were soldered. This copper oxide mixture caused considerable troubles in firing by penetrating the porcelain and running down on the insulators, so that this method was eventually abandoned.

Sprayed Metal Surfaces

Special coatings of a non-conducting composition have been applied to porcelain resulting in a rough, finely pitted surface, to which metallic copper is sprayed with a Shoop metal-spray gun to produce a fully conducting ground shield on the insulator. [2][3] For this purpose, the Locke No. 2008 matte glaze is used.

Ceramic "Rescons"

In 1958 a series of semi-conducting coatings were developed for the purpose of regulating the distribution of voltage stresses across the surface of porcelain bushings, such as shown in sketch, Figure 5.

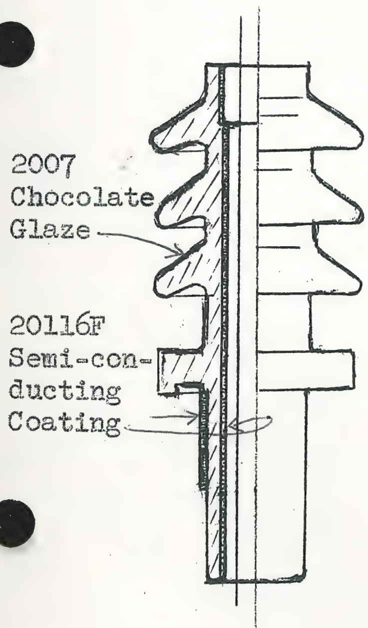

Figure 5. Bushing V93116

One of these compositions (No. 20116F), contains 43.5% Fe_2O_3, 12% ZnO and 4.5% CoO and its resistivity range is from 6.7 to 3.1 megohms/sq. cm., depending upon the thickness of the glaze.

This ceramic coating is applied to the interior and exterior surface of the bushings as shown in the sketch. The application should be 2 to 3 mils as the strength of the porcelain and the resistivity of the coating are lowered with increased thickness.

(1) Westinghouse Patent 1.987,683 (1935)
(2) Ohio Brass Patent 2,119,989 (1938)
(3) Locke Patent 2,264,152 (1941)

As an improvement in the performance of suspension insulators, especially under humid weather conditions, two British porcelain manufacturers (1) in 1949 presented an interesting development consisting of semi-conducting glazes applied over the entire surface, as shown in Sketch, Figure 6.

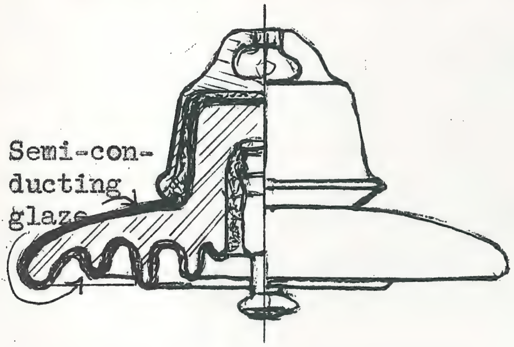

Figure 6. Typical Insulator (Bullers.)

The object was to provide a definite ohmic resistance and with a constant voltage applied, the resulting current would raise the temperature of the insulator which would then keep dry and perform better under conditions of fog and surface dirt.

Coating the entire insulator surface

The semi-conducting glazes in question consisted of ordinary ceramic glazes containing 35-45 parts of oxide mixtures of iron, chromium and zinc which in firing form mixed crystals ($ZnCr_2O_4$ and Fe_3O_4 spinels), responsible for the main conducting of the glazes which was of the order of 50 megohms per square.

<u>Failures in Service Due to Electrolytic Corrosion</u>

The Insulator Department obtained some of the coated British insulators. Chemical and X-ray analyses were made and duplicate glazes, containing similar amounts of Fe_2O_3, Cr_2O_3 and ZnO mixtures applied to Locke suspension insulators. The surface resistivity of the Locke glazes were of the order of 34-72 meg./per square. In testing these and the British insulators it was found that as the applied voltage was increased, the resistance decreased and eventually resulting in the generating of heat on the surface high enough to crack the insulator. Later reports from England noted that the performance of such resistance coated insulators in the field was disappointing, as the conducting glazes showed poor durability and weather resistance and in some cases became unservicable in a few weeks. The deterioration of these semi-conducting coatings in service was due to electrolytic corrosion occuring at the interface with surface films of water.

(1) Bullers Ltd., and Taylor, Tunnicliff & Co., Patents 1949

In contrast to such unstable coatings, the new Baltimore 9001-C meta glaze covered with the regular 2007 brown silicate glaze, showed no deterioration or changes in resistivity after a lengthly test exposure in sulfuric acid solution or hydrogen-sulfide and nitric oxide gases.

Chapter XIII. Kilns and Firing Process

History

Development

Trends

The importance of heat treatment in the manufacture of electrical porcelain has always been recognized from the beginning of the industry.

As a matter of fact, the action of heat on clays and related silicates is the very foundation of the industry. It is only through a prolonged firing process that dried insulator shapes obtain the mechanical strength, density and dielectrical properties required from a high voltage insulator.

The days of the century old style pottery kilns with their typical smoke stacks and coal firing fire boxes have gone. For more than 30 years they were the only available firing facility for porcelain insulators, here and in England. In Germany and France, two-story kilns were in use, the upper part for bisque firing to 900°C and the lower part for "ghost" firing, i.e. glazed ware to higher temperature - cone 14 (1400°C).

There were 16 round coal fired kilns (18" diameter) at Baltimore and 14 ($16\frac{1}{2}$") at Schenectady. Also, two round muffle kilns for firing large sectional bushings. The insulators were placed in round or square "saggers", i.e. refractory containers and these were stacked one on top of another and the vertical stacks filled in ring formation. The firing cycle was from 72 to 85 hours, cooling 3 days and

Figure 1. Kiln Stacks and Damper - Schenectady Plant

to empty the kiln required another day.

To obtain uniform heat distribution in the updraft kilns was not always an easy problem. It was, especially before these kilns were later changed into up-and-down draft construction, not uncommon to find porous ware (on top) and overfired ware around the outside bottom ring near the fire boxes. This method of firing porcelain was extremely wasteful and expensive in labor required to load, fire and unload these kilns. Only 20% of the imput of heat was actually utilized, the remainder lost in heating kiln furniture, walls and stacks.

Figure 2. Coal Fired, Bottle Shaped Porcelain Kiln - Schenectady

In 1912 the first continuous car tunnel kiln made its appearance in American at the General Ceramics Company at Keasley, New Jersey. This kiln, a German (Didier-March) design, was coal fired and the ware (stoneware ceramics) was fired in sagers.

First American Tunnel Kiln at General Electric

Encouraged by the success with this kiln, the General Electric Company at Schenectady built in 1913 such a kiln, 180 feet long, containing 36 cars. This kiln was also coal fired with two producer type furnaces on each side. With 12 cars per day the total cycle was 72 hours. The General Electric Company thus became the American pioneer in firing electrical porcelain in car tunnel kilns.

This kiln was in later years converted to gas firing (Surface Combustion Company), with city gas (550 BTU) as a fuel.

The other manufacturers of electrical porcelain were also quick to recognize the economic advantages offered by these type of kilns, such as a comparatively cross-section subject to heat treatment, continuous operations and improved quality of the ware. A saving of 70% in fuel cost and 50% in labor cost over that of the round periodic kiln was later realized in most tunnel kilns.

The first tunnel kiln at Locke-Baltimore was built in 1924. This kiln (Harrop) was 368 feet long, contained 48 cars and was oil fired. It was in continuous operation for 31 years when it was replaced in 1955 with a new Allied 363 foot gas fired kiln. Some of the old Baltimore round periodic kilns and the old Harrop (No. 1) tunnel kiln are shown in attached large photograph. Later, all round periodic kilns were dismantled and firing capacity increased by the addition of three other Allied (first oil fired, then gas fired) tunnel kilns. No. 2 in 1937, No. 3 in 1912, and the shortest one (No. 4) in 1949.

<u>Baltimore First Tunnel Kiln</u>

There have been only three tunnel kiln builders - Harrop, Dressler and Allied, in this business, each with his own ideas and designs incorporated in their kiln construction. Some of these installations, especially the earlier ones, were disappointing from the standpoint of control and of the quality and uniformity of the fired insulators. As long as saggers were used, the situation was not so bad, but when open (deck) firing became a new method of firing porcelain, the older kilns with only a few furnaces on each side and their concentrated and impinging direct heat caused much loss of ware due to over firing (bloat) and discoloration of the glazes. The old Harrop kiln at Baltimore was a good example of such continuous firing difficulties.

<u>Kilns and Firing Facilities in Industry</u>

The type of kilns, facilities and firing schedules of the most prominent electrical porcelain manufacturers have been tabulated in Tables I and II. While the kiln data, supplied by the kiln builders, are quite correct and complete, the firing schedules do not necessarily represent up-to-date conditions, as these vary with business conditions and production demands.

Each of these insulator manufacturers has, today, at least two tunnel kilns, usually one or two long and one shorter one. The present trend is to build shorter kilns rather than very long ones. The age-old problem of securing satisfactory distribution of heat both in the corss section and in the length of the preheating zone has now been mastered in modern kiln designs. The Swindell-Dressler Co. in 1931 introduced the multiple burner idea with very good results, especially in gas fired kilns. This system has also been adopted now by the Allied people. The old No. 1 Harrop kiln, for instance, had only 6 burners on each side (oil fired), a total of 12 burners, whereas the new gas fired Allied kiln has a total of 59 burners, giving a more uniform heat distribution. The elimination of a

direct impact of hot gases on the ware has been obtained, resulting in top grade ware and much faster firing rates.

Photograph, Figure 4 shows the multi-burner system at the high fire zone of kiln No. 2. This kiln has 37 burners on each side.

Figure 4. Checking pyrometric cones through opening in furnace wall. Optical pyrometric (temperature) readings are also taken through such peep holes.

Firing electrical porcelain has changed from an art of earlier days to present methods based on combustion engineering and ceramic engineering knowledge. From a practical application, certain rules must be observed, namely:

Some Rules for Good Firing Practice

a.– Hot kiln gases must be directed under or over but never directly against the ware, i.e. no impinging flame should at any point strike the ware.

b.– Sufficient circulation must be provided through and around the loaded car. An 8-10 inch flue should be allowed under the car bottom. Photograph, Figure 5 shows good and bad loading practice.

Figure 5. Note 8"Flue Under Bottom Deck, Absent at Right, Blocking Circulation

c.– To hold the heat on the top in the kiln, cars should be loaded to the top or baffles, or bricks should be placed there.

d.– Car bottoms should be sealed tight to prevent cold air leaks, using asbestos aprons.

e.– The ware, entering the kiln, should be dry, i.e. should not contain more than 0.5% moisture

f. – Select the proper place on the car for the various sizes and shapes of insulators to be fired. Al_2O_3 coated firing rings and washes must be used on all ware susceptible to distortion.

g. – Use sets of pyrometric cones on top, middle and bottom of cars. These simple ceramic cones have been the guide for quality firing for many years because of their sensistivity to the three basic variables of firing - temperature, time and atmosphere.

Kiln Designs - Firing Data

Baltimore Kiln Data

It goes beyond the scope of this chapter to describe in detail the various kiln constructions and temperature and draft control instruments. Information on these and general operating instructions are furnished by the kiln builders and instrument manufacturers.

However, a simple schematic kiln layout is shown on Kiln Data Sheets, Figures 6, 7, 8 and 9 for the four Baltimore Allied tunnel kilns. Time-temperature firing curves for tunnel kilns No. 1 and 3 and for one of the periodic kilns are presented in diagram, Figures 10 and 10A.

Firing Process

Basic Objectives of Firing

As shown in the above curves, the firing of porcelain insulators, as all vitrified ceramic ware, is both a time and temperature combination within certain limits.

The basic objectives of the firing operation, as the ware travels progressively through the three zones, namely preheating, firing and cooling are:

a. – The removal of pore water, (preheating) usually completed at 400°F. — Dehydration

b. – The burning out of carbonaceous matter and removal of the chemical combined water, completed around 1650°F. Kilns are fired during this period with excess air (125%) for complete oxidation of the ware. — Oxidation — Excess Air

Avoid as much as possible highly lignitic or high organic bearing ball clays in the plastic body. This subject was previously discussed in the chapter on ball clays and body composition.

The present GE. 740-1 plastic body is very low in such carboneous matter.

Time-Temperature Firing Curves

Baltimore and O. B. Kiln Schedules

The two diagrams, Figures 10 and 10A, show time-temperature firing curves for Baltimore and Ohio Brass Co. tunnel kilns and for one of the Baltimore periodic kilns for firing large porcelain bushings.

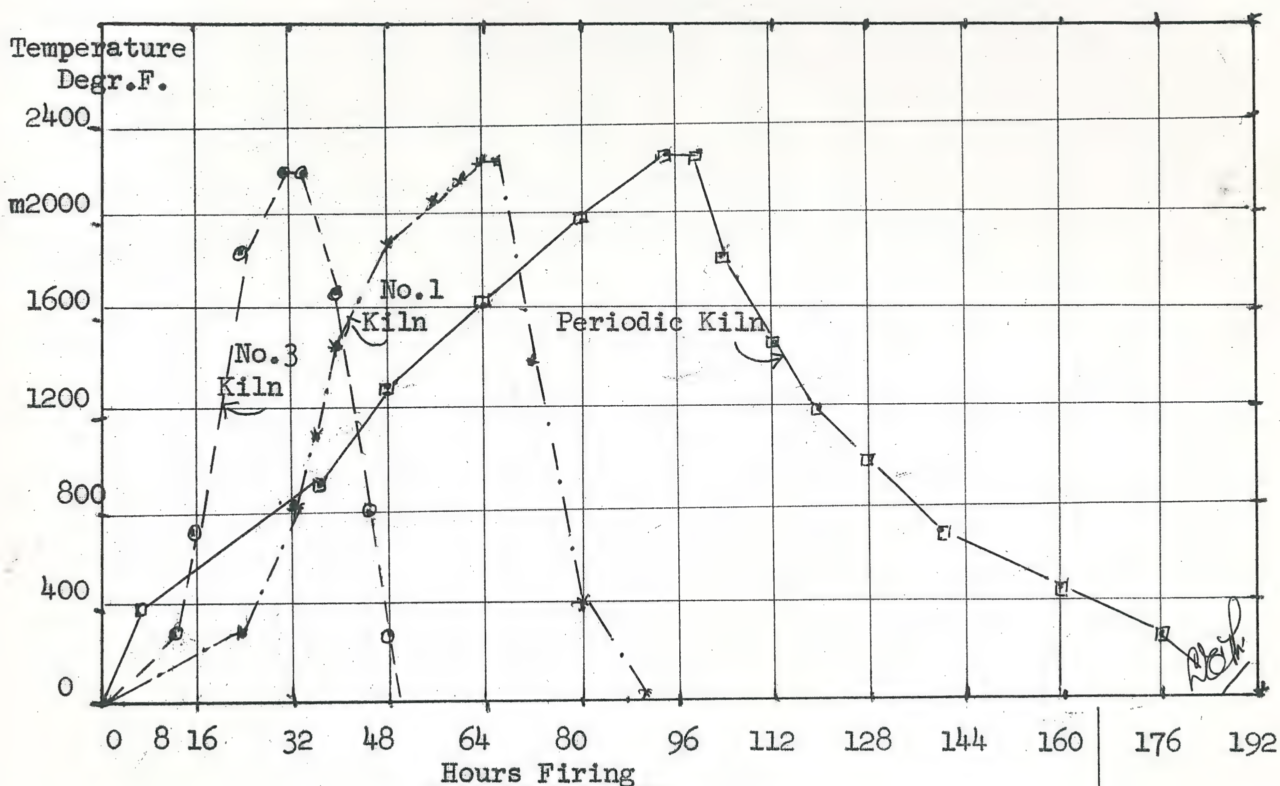

Figure 10. Baltimore Kilns No. 1 and No. 3. 18 cars per day schedule. Note present fast rise of temperature in periodic kiln during first four hours firing. This requires completely dry ware, more than slight pore moisture has produced "blow-ups" in insulators, scattering fragments on all surrounding ware, causing expensive manufacturing loss.

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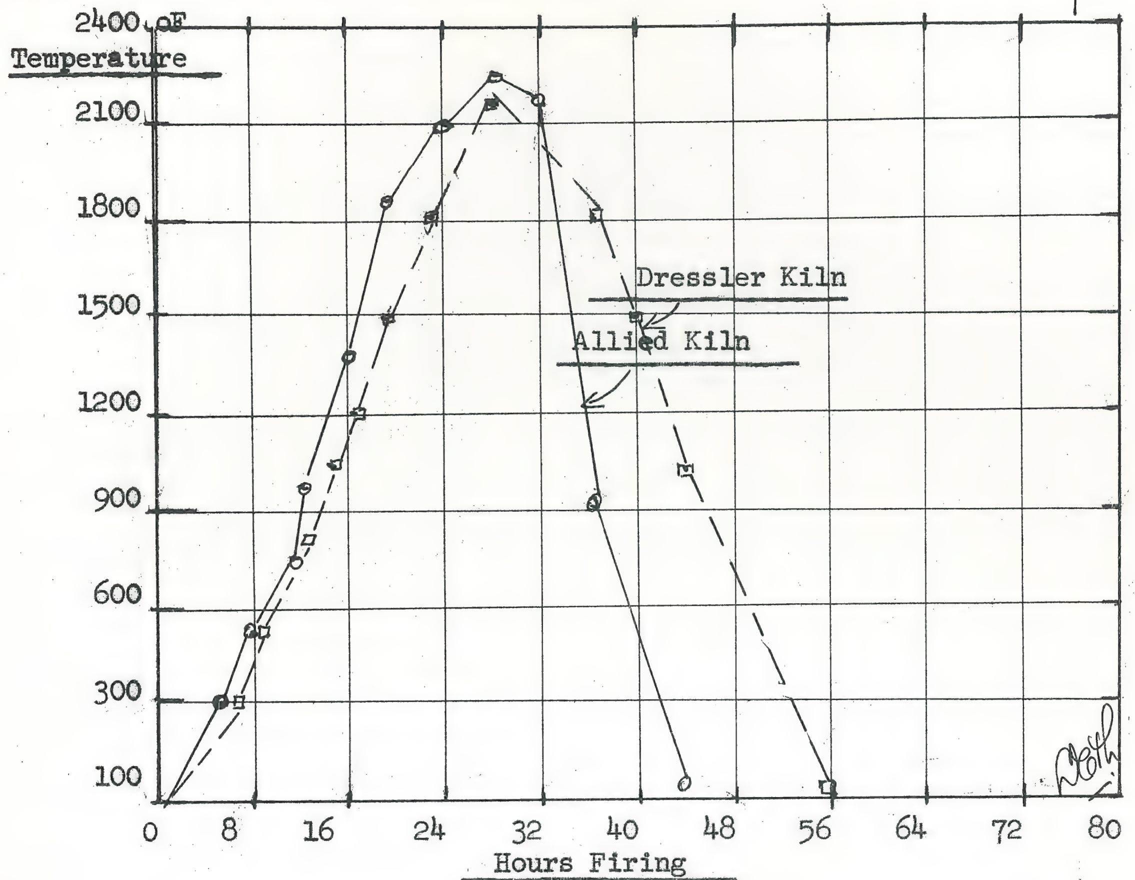

OB.Kilns

Firing Curves

Figure 10A - Ohio Brass Time-Temperature Curves Allied and Dressler Tunnel Kilns

Comparison of Firing Schedules

Firing Cycle

	Ohio Brass Company Kiln #1	Kiln #2*	G.E. Balto. Kiln #1
Up to Max. Temp.	27	28	31
Cooling	19	26	17
Total	46 hrs.	54 hrs.	48 hrs.
Length of Kiln	366'	220'	363'
Cars/Day	22	12	24

*Dressler kiln used for larger bushings, some fired in saggers.

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The new Ohio Brass Allied kiln is fired in 46 hours which equals G.E. Schedule of No. 1 for 24 cars per day. This is the fastest schedule for this No. 1 Baltimore kiln.

Photograph, Figure 10-B, shows car loaded with ware for new Allied kiln. This kiln has a smaller cross-section and no preheater (kiln drier). See Table on Tunnel Kiln Data.

Ohio Brass Tunnel Kiln Car

Mixed Load

Figure 10-B Ohio Brass Kiln - 46 Hr. Schedule

Note: Flue under lower deck, similar to Baltimore cars. Four sets of pyrometric cones (9-12) on car.

-To Page 149-

c.- To bring about essential chemical and (vitrification peroid) mineralogical reactions to a degree of completion required.

Vitrification

A limited period of soaking at the top temperature is desirable for the proper diffusion of the glasy phase developed, as well as obtaining the maximum density.

d. - To achieve these objectives with a minimum time, cost and loss.

Cooling

Cooling the fired ware is relatively easy as compared with heating up. The only critical period is when the ware passes through the $\alpha-\beta$ quartz inversion temperature (1067°F). If the ware is cooled too fast, "dunting" cooling cracks, identified by hair line cracks and a smooth, conchoidal fracture, may suddenly develop. On the other hand, when large insulators are refired, heating up must also be slow through this reversible quartz inversion temperature, as otherwise the same type of cracks will develop.

Kiln Dryers

Waste Heat

Utilization

The Baltimore tunnel kilns are, as the only ones presently in the insulator industry, operated in conjunction with "kiln" dryers, with waste heat supplied from the exit end of the tunnel kilns. By this arrangement glazed insulators, still containing up to 4% moisture, may be loaded on the cars, which has the advantage that drying cycles can be shortened and, in general, the flow of production in the plant is increased. In other insulator plants, waste heat is generally utilized for heating operation space and plaster molds, etc.

Much of the former mysteries and uncertainties of what goes on behind the furnace walls during firing has been removed by studies of the physical and chemical reaction in bodies and glazes in the firing process.

Extensive firing tests to various temperatures of insulators and test cylinders made at the Baltimore Ceramic Laboratory have supplied valuable technical information and answers to such important questions as:

a.- What is the firing range of the present 740-1 plastic body? At what cone (temperature) is the body overfired?

b. - How fast may insulators be safely fired and at what temperature are maximum density and mechanical strength be obtained? etc.

The insulators and test cylinders were fired to kiln temperatures from 1650°F to 2400°F, which converted the chalky, porous and low strength body into the hard, dense and high strength material known as electrical porcelain.

Photograph, Figure 10 shows half sections of suspension insulators used in this firing test.

Figure 10. Insulators Used for Experimental Firing

Shrinkage data, density and mechanical strength are plotted on diagrams, Figure 11 and Figure 12.

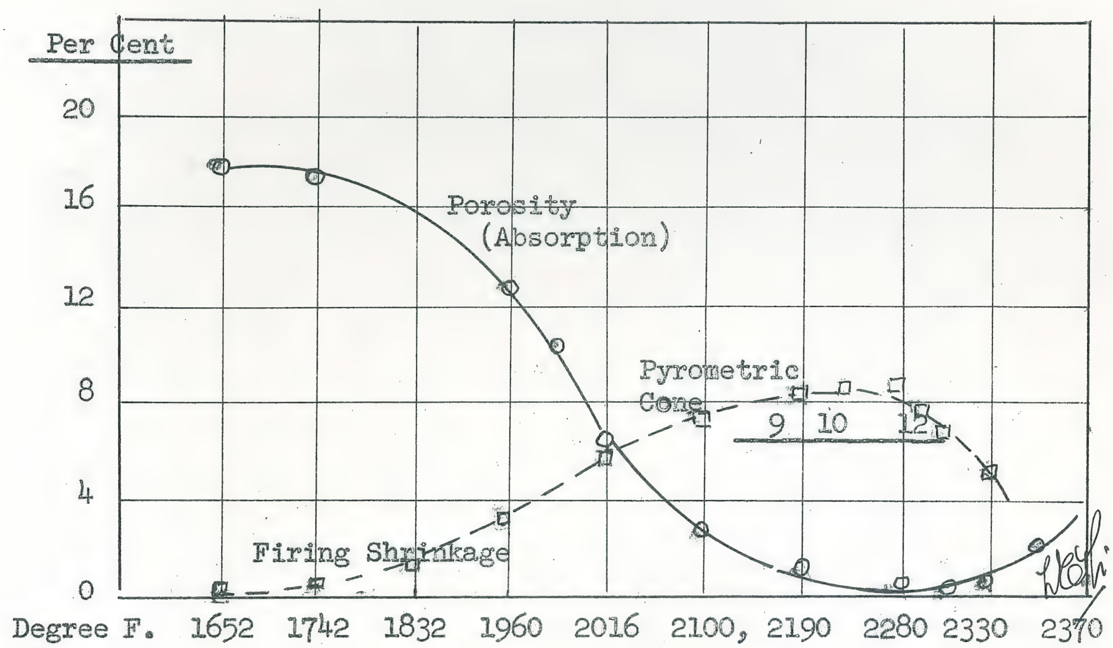

Figure 11. Firing Temperature Vs. Shrinkage and Porosity

The sharp decrease in porosity and increase in firing shrinkage is due to the fusion of potash feldspar which has a melting point of approximately 2100°F. Above cone 10-11 the shrinkage again decreases due to over firing of the body.

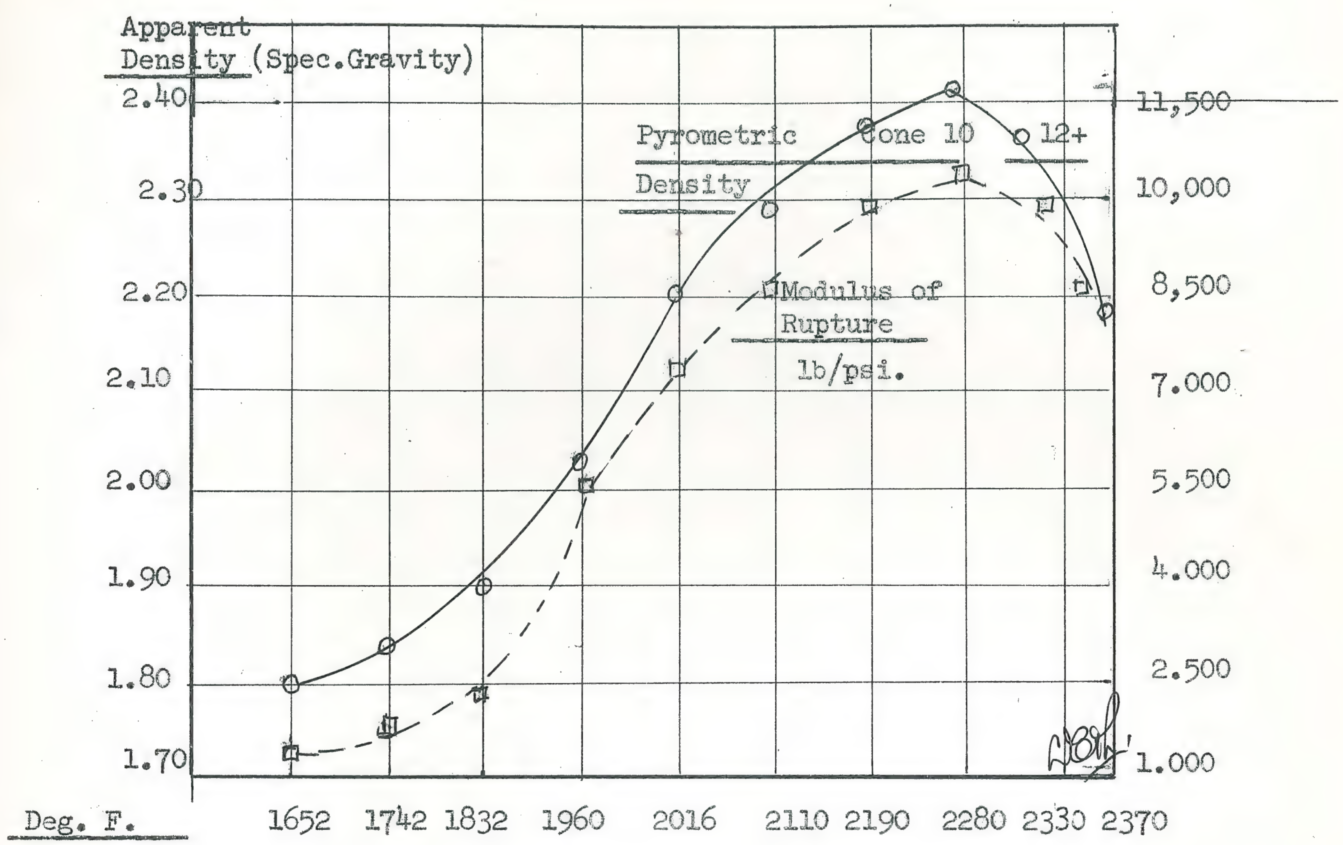

Figure 12. Firing Temperature Vs. Density and Mechanical Strength

The results show that the highest mechanical strength in the No. 740-1 plastic body is obtained at 2280°F (pyrometric cone 10). With increase in firing temperature the strength begins to drop.

The firing range of the present 740-1 plastic body was found to be between pyrometric cone 9 and 10-1/2 which is entirely satisfactory for commercial kiln firing.

Of considerable aid in these firing studies have been the petrographic microscope and the X-ray diffraction apparatus. The former shows if porcelain is underfired or properly vitrified; by feldspar solution, by the reaction of the glass on quartz grains and by the development of crystallized, interlocked patches of mullite. An illustration of a well vitrified electrical porcelain is shown in photomicrograph Figure 13.

Figure 13. Thin Section of Fired Porcelain Body
Cone 10, 450X Polarized Light

A sample of over fired porcelain is shown in photomicrograph Figure 14, Gases that have developed at the high temperature have ruptured the glassy bond, and produced a vesciular structure. Low mechanical and low dielectric strength are the result.

Figure 14. Thin Section of Over Fired "Bloated" Porcelain. Cone 13

Microstructure and Mechanical Strength

It has been believed in former years that highest strength in electrical porcelain was entirely dependent upon a maximum amount of mullite developed in firing. This is not quite true, however, in the light of more recent studies of the microstructure by microscopic and X-ray diffraction anlayses.

By correlating the mullite and glass content with the mechanical strength of fired porcelain specimens, we find that the total amount of mullite and glass rather than mullite alone up to a point, gives the highest strength values. (10-11,000 lb/psi for unglazed porcelain). This total glass-mullite content at cone 10, i.e. the most favorable firing temperature is 82% with the remainder of 18% being uncombined quartz (flint).

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As the result of all this research on the rate of firing and fired porcelain structures, we have been able to considerably shorten firing schedules with improved quality ware and substantial fuel savings.

Increased Firing Schedules Resulting from Research

Whereas we, not too many years ago, fired Baltimore tunnel kilns from 52 to 96 hours (12 cars per day) these kilns are now fired from 39 to 66 hours - up to 24 cars per day with no porosity, (under firing) or bloating (over firing) of the insulators.

Large porcelain bushings or such of difficult design are for technical and economical reasons best fired in the large periodic kilns. Baltimore has now three gas fired rectangular downdraft kilns, the Westinghouse Company at Derry, Pa., has four similar kilns and four "beehive" round gas fired kilns are at the Ohio Brass Company.

The firing takes about 100 hours and the cooling from 72 to 96 hours. A time-temperature curve for one of the Baltimore kilns is shown in Figure 16.

Figure 15. Loading Ware.

Dressler Periodic Kiln
Length (inside) 30' Width
8'8" **Height 10'** to Crown
Natural Gas Consumption -
186-240,000 cu.ft. for
complete firing.

10-C

This photograph shows the loading of large bushings in one of the Ohio Brass gas fired periodic kilns. firing some in saggers. 100 hours firing to maximum temperature.

Note that some of the large insulators are lifted with a cable attached to an inflated rubber bag inside the insulator. That is the same method used by Westinghouse at their Derry Plant.

Electric Kilns

Types and Firing Problems

Electric Kilns

Considerable interest in the firing of porcelain insulators in electric kilns has been shown since the installation and operation of an electrically heated double-tunnel kiln at the Porzellanfabrik Langenthal in Switzerland in 1935. This kiln, built by Brown Boveri, is 327 feet long and has 66 cars in the high fire zone where glazed electrical and other porcelain ware is fired to 1410°C (Cone 14) to vitrification in a 67 hour cycle. The other tunnel is heated partly by waste heat and auxiliary heating units (glow bars) for (unglazed) bisque ware.

In Switzerland, where no natural gas is available and oil and coal must be imported, electricity is the lowest cost source of heat. We see then, that economics govern here, and that goes for other locations, the type of fuel used for firing ceramic ware.

However, electrically heated tunnel kilns have been built in recent years in West Germany (Siemens and Brown Boveri) and in England, most for glost firing and decorating dinnerware. Here, the maximum temperature varies between 900°C and 1000°C.

The heating units are Glow Bars, (silicon carbide) or, what are now considered superior, Kanthal (Swedish) heating elements.

Apart from the high cost of electricity at the present time, there are other factors which today prevent the building of electrically heated car tunnel kilns. One of these factors, and surely an important one is the problem of transferring the heat from the source to the ware and across the width of the car. In gas-or oil-fired kilns, the heat transfer is by convection, with minor transfer by conduction and radiation. In electrically fired kilns only in the lower temperature ranges (preheating zone) is the heat transferred by convection and in the higher temperature range (high fire zone) probably as high as 90 percent by radiation. Therefore, all electric kilns have been built with a much narrower cross section and with smaller cars carrying much less ware than in tunnel kilns heated with other fuels. This means lower kiln output and, again, higher firing costs in electric kilns.

A number of periodic and continuous (car type) high fire electric kilns have recently been built in this country, most of them by the Harper Company, but so far none for conventional electrical porcelain, all for higher fired alumina and ferrite ceramics. The most interesting is the new 145 ft. tunnel kiln at General Ceramics at Keasbey, New Jersey. This kiln has 60 cars, 2' long, 22" wide and 24" high (setting space) and is heated by Glow Bars, firing ferrite ceramics to 2470°F under reducing atmosphere.

In conclusion of this chapter on Firing Process it may be expected that some time in the future electrical porcelain will also be fired in continuous electric kilns. But before this can be done economically, the cost of electric power must be considerably reduced in order to compete with presently used lower cost fuels.

Re-Fired Insulators

In every insulator plant there are fired insulators rejected during inspection because of slight superficial defects such as spots, rubbed-off glaze due to careless handling or kiln dirt, etc. These insulators are touched up with new glaze and reclaimed by refiring at regular kiln schedules. The amount may be from 5-15 percent; at the present time there are 8% reclaims of pintype, 5-6 percent of suspension insulators and 10-12% for jiggered ware.

Apart from the cost of reclaiming this ware, there is another factor to be considered, namely the loss of mechanical strength due to refiring. That raises the question, how many times can an insulator be refired?

Effect of Repeated Firing

The answer can be found from results plotted in curve, Figure 16. These are refired unglazed and glazed test cylinders.

Similar re-firing tests were made on suspension insulators and there we find that the M & E strength of once refired, assembled insulators was reduced by 10% and the impact strength reduced by 15 percent.

With mechanical strength of Baltimore suspension insulators, presently well above the NEMA strength requirements, one more firing can be condoned, but after that the insulators would be unacceptable. With most apparatus porcelains, this matter is never that serious, however, there also the effects of refiring on strength should be considered. But, here also, as has been discussed before in the chapter on glazes, several coats of glazes applied for refiring also weaken the porcelain.

When electrical porcelain is repeatedly fired an increase in the glassy phase takes place and eventually the porcelain will "over fire" and bloat and lose most of its strength.

Loss in Mechanical Strength

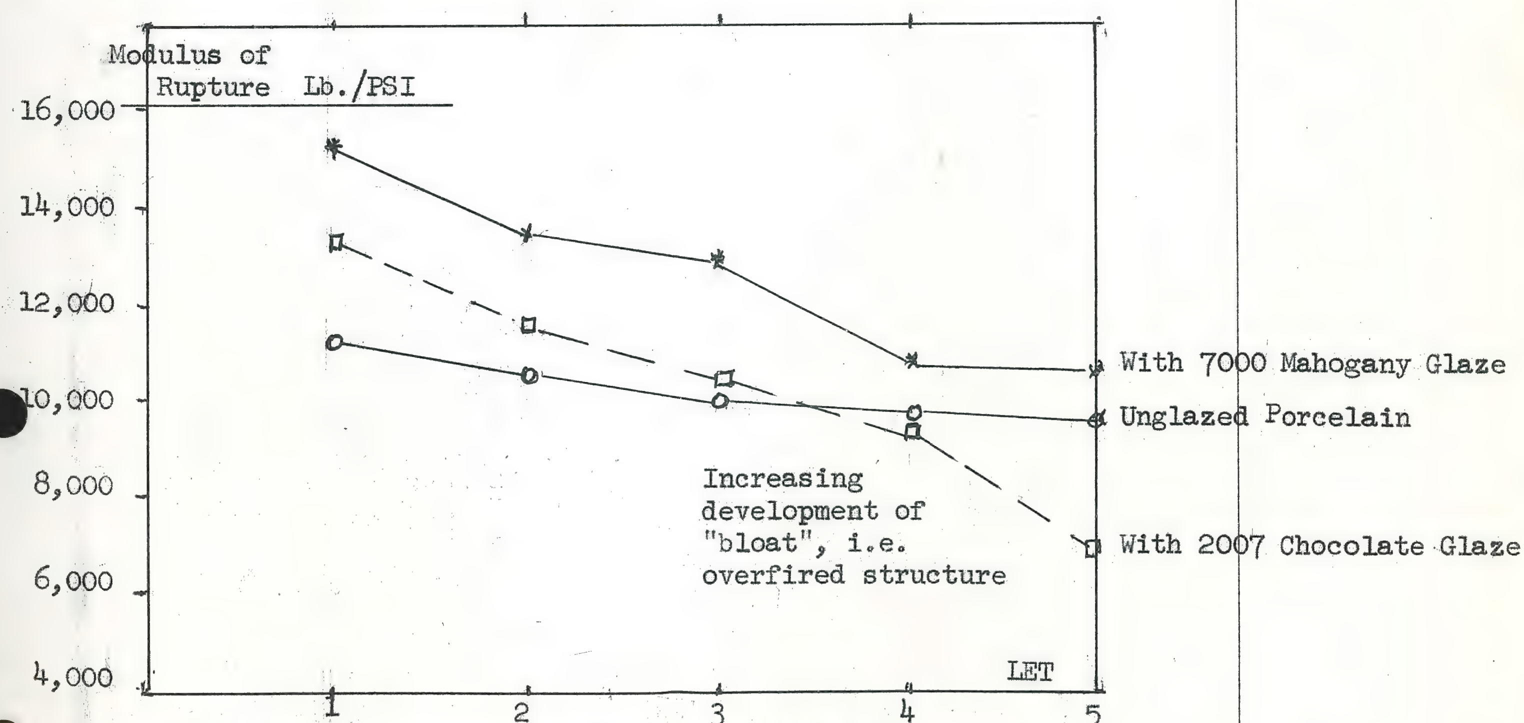

Figure 16. Effect of Number of Firings Upon Repeated Mechanical Strength of Unglazed and Glazed Locke Porcelain

Baltimore Kiln No. 1 (Allied)

No. Cars Per Day	Time Per Car		Dryer Time		Firing Time		Cooling Time		Total Time Fired		Total Time Drying & Firing	
	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.
12	2	-	36	-	62		34		96	-	132	-
13	1	51	33	18	57	18	31	24	88	42	122	-
14	1	43	30	54	53	12	29	12	82	24	113	14
15	1	36	28	48	49	36	27	18	76	54	105	42
16	1	30	27	-	46	30	25	30	71	-	98	-
17	1	25	25	30	43	54	24	-	67	54	93	24
18	1	20	24	-	41	14	22	36	63	50	87	50
19	1	16	22	48	39	12	21	48	61	-	83	48
20	1	12	21	36	37	13	20	24	57	37	79	13
21	1	09	20	42	34	36	19	30	54	06	74	48
22	1	05	19	30	33	30	18	25	51	55	71	25
23	1	03	18	54	32	33	17	51	50	24	69	18
24	1	-	18	-	31	-	17	-	48	-	66	-

Baltimore car tunnel kilns are all similar to the one shown in schematic sketch.

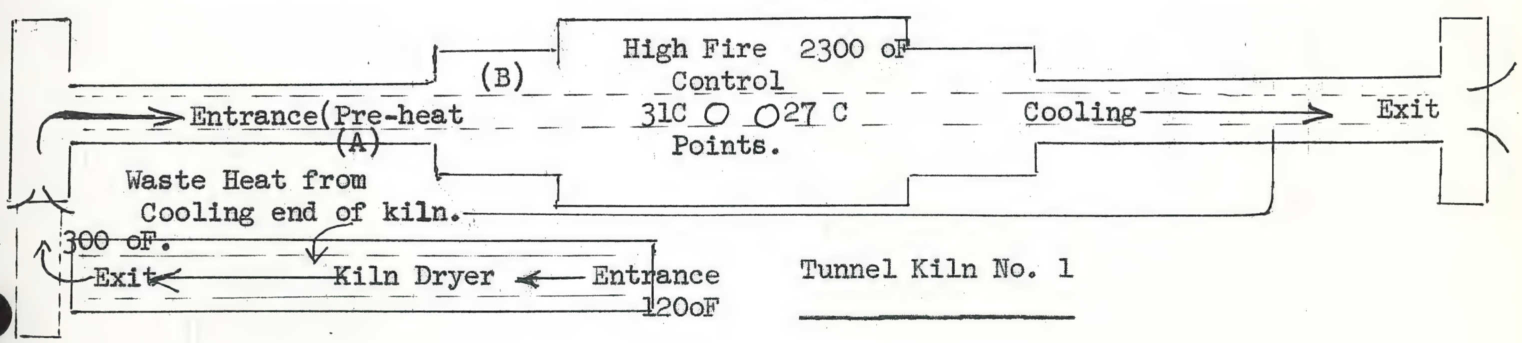

Fig. 6.

Kiln No. 1 is 363 fr. long. Kiln Dryer 126 ft. long.
48 cars 18 cars.

The burner equipment on the Baltimore kilns consist of North American aspirator burners manifolded to give two point control in high fire zone. Other thermocouples are distributed in the crown over the length of the kilns.

Besides the pre-heat zone, another zone, the peddler zone (B) was installed to obtain a time-temperature cycle of the entering ware only obtainable with gas.

Other kiln data, car dimensions and gas consumption see Kiln Data Sheet Table I.

Firing Schedules Kiln No. 2

Length 370'0"   Capacity 49 Cars   Car Length 87"   Drier Capy. 18

No. Cars Per Day	Time Per Car		Dryer Time		Firing Time		Cooling Time		Total Time Fired		Total Time Drying & Firing	
	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.
12	2	-	36	-	54	-	44	-	98	-	134	-
13	1	51	33	18	49	57	40	42	90	39	123	57
14	1	43	30	54	46	21	37	46	84	07	114	61
15	1	36	28	48	43	12	35	12	78	24	107	12
16	1	30	27	-	40	30	33	-	73	30	100	30
17	1	25	25	30	38	15	31	10	69	25	94	55
18	1	20	24	-	36	-	29	20	65	20	89	20
19	1	16	22	48	34	12	27	52	62	04	84	52
20	1	12	21	36	32	24	26	24	58	48	80	24
21	1	09	20	42	31	03	25	18	56	21	76	63
22	1	05	19	30	29	15	23	50	53	05	72	35
23	1	03	18	54	28	21	23	06	51	27	70	21
24	1	-	18	-	27	-	22	-	49	-	67	-

Figure 7. No. 2 Allied Kiln. Gas Consumption 24 Hours 220,000 Cu.Ft. Used for Apparatus Porcelain, Pin Type Insulators.

Firing Schedules Kiln No. 3

Length 200'0"   Capacity 26 Cars   Car Length 87"   Dryer Capacity 10

No. Cars Per Day	Time Per Car		Dryer Time		Firing Time		Cooling Time		Total Time Fired		Total Time Drying & Firing	
	Hrs.	Mon.	Hrs.	Mon.	Hrs.	Min.	Hrs.	Min.	Hrs.	Mon.	Hrs.	Min.
10	2	24	24	-	38	24	24	-	62	24	86	24
11	2	11	21	50	34	56	21	50	56	46	77	96
12	2	-	20	-	32	-	20	-	52	-	72	-
13	1	51	18	30	29	36	18	30	48	06	66	36
14	1	43	17	10	27	28	17	10	44	38	61	48
15	1	36	16	-	25	36	16	-	41	36	57	36
16	1	30	15	-	24	-	15	-	39	-	54	-
17	1	25	14	10	22	40	14	10	36	50	51	-
18	1	20	13	20	21	20	13	20	34	40	48	-
19	1	16	12	40	20	16	12	40	32	56	48	-
20	1	12	12	-	19	12	12	-	31	12	44	96
21	1	09	11	30	18	24	11	30	29	54	43	12
22	1	05	10	50	17	20	10	50	28	10	41	24

Figure 8. Kiln Used Primarily for Firing Suspension and Fog Type Insulators at a Schedule Between 16 and 22 Cars/Day. Gas Consumption Approx. 156,000 Cubic Feet/Day.

Firing Schedules Kiln No. 4

Length 165'0" Capacity 25 Cars Car Length 75" Dryer Capacity 10 Cars

No. Cars Per Day	Time Per Car		Dryer Time		Firing Time		Cooling Time		Total Time Fired		Total Time Drying & Firing	
	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.	Hrs.	Min.
10	2	24	24	-	36	-	24	-	60	-	84	-
11	2	11	21	50	32	45	21	50	54	35	76	25
12	2	-	20	-	30	-	20	-	50	-	70	-
13	1	51	18	30	27	45	18	30	46	15	64	45
14	1	43	17	10	25	45	17	10	42	55	60	05
15	1	36	16	-	24	-	16	-	40	-	56	-
16	1	30	15	-	22	30	15	-	37	30	52	30
17	1	25	14	10	21	15	14	10	35	25	49	35
18	1	20	13	20	20	-	13	20	33	20	46	40

Figure 9. Kiln No. 4 is the Smallest of the Baltimore Kilns. The Cross-Section is Narrower than that of the Other Tunnel Kilns.

Kiln No. 4 is Considered More or Less as a Stand-by Kiln. Fuel Consumption Approx. 116,000 Cubic Feet/Day.

Firing Difficulties - Cause and Cure

With present modern tunnel kilns and temperature control equipment, firing difficulties should be at a minimum. However, even with all these difficulties have occurred from time to time of which the most common are herewith discussed.

Firing Difficulties

Common Causes and Cure

1. Blowing Up or Cracking of Insulators in the pre-heating zone, indicated by a rough fracture or partial rupture or complete disintegration of the insulator. In practically all cases the pieces were too wet and contained more than one half of a percent moisture which is the upper limit for safe firing at fast kiln schedules.

2. Blue Coring in Center of heavier section, caused by moving the ware too fast through oxidation zone or lack of excess air in this area which should be between 130 and 150 percent. Make gas analysis to determine amount of CO_2 present. Excess air in kiln firing may be good or bad, depending where it is found. At the high fire zone, it should be low (40-50%) or heat is wasted; at the cooling zone and exit end practically pure air should be present.

3. Cooling Cracks (Dunting) indicated by a fine hairline crack, and when broken by a conchoidal fracture. The defect may occur by cooling the ware too fast in the critical zone (1057°F - see page 150).

4. Non Uniformity of Heat Distribution through load, temperature difference between bottom and top from entrance to maximum temperature in the high fire zone. Pyrometric cones have then been placed all-over the cars, but while these may show the total difference in applied heat, these cones cannot show the location of temperature in the kiln. Traveling thermocouples attached to the bottom and top load shows the difference and when plotted the complete thermal history of firing is obtained.

5. Good Maintenance in kiln furniture, carborundum posts and slabs and construction is necessary to prevent collapse of the load and car wrecks, and eventually complete shut down in the kiln. Kiln furnitures should be cleaned from chips and sand which deposit and fuse on the ware.

6. Thermocouples should be periodically checked with optical pyrometer.

Table I. Tunnel Kilns and Firing Methods in Electrical Porcelain Industry

Length	Car Dimensions Width	Car Dimensions Height	Car Dimensions Length	No. of Cars	Cars Per Day Min.	Cars Per Day Max.	Total Cycle Hours (Firing & Cooling) Min.	Total Cycle Hours (Firing & Cooling) Max.	Max. Temperature of Pyrometric Cone	Type of Fuel Consumption/24 Hrs.	Remarks
363'	6'4"	5'7"	7'3"	48	12	24	48	36	2200-2210°F cone $9\frac{1}{2}$ to $11\frac{1}{2}$ (bottom)	nat. gas. 225,000 cu.ft.	
362'6"	6'4"	5'7"	7'3"	49	12	24	49	98		" " 225,000 "	
159'9"	6'4"	5'7"	7'3"	26	10	22	28	62		" " 134,000 "	
162'6"	4'6"	5'	6'3"	25	10	18	33	60		" " 116,000 "	
re exchangeable in kilns No's. 1, 2 and 3.											
398'	5'8"	5'2"	7'9"	50	8	16	66	150	2300°F 9-$10\frac{1}{2}$	City gas (550 BTU) 250,000 cu.ft.	Standby kiln. Very few firings made in this kiln.
283'	5'8"	5'2"	7'9"	35							
ilns dismantled. The No. 2 kiln purchased built at Illinois Porcelain Plant in 1957.											
381'10"	5'10"	5'8"	6'6"	57	16		56	112	2300°F cone $10\frac{1}{4}$-$10\frac{1}{2}$	Oil or nat. gas 1150 gal oil - 230,000 cu.ft.gas	Harrop kiln has been rebuilt several times. Some insulators fired in saggers.
348'	5'10"	5'8"	6'6"	24	10		66				
380'	4'4"	5'1"	7'9"	30	16		51		2310°F cone 11-12	Nat. gas or oil (stand-by)	Harrop kiln rebuilt in 1956 by Allied. Large porcelains fired in Dressler kiln. New kiln see Figure 10-B.
220'	4'4"	5'1"	7'9"	28	12		56				
366'	4'4"	5'1"	7'9"	47	24		46				
rs interchangeable. O.B. kilns have a narrower section than G.E. (Baltimore) kilns.											

Table I. Tunnel Kilns and Firing Methods in Electrical Porcelain Industry

	Insulator Manufacturer and Kiln Builder	Length	Car Dimensions Width	Height	Length	No. of Cars	Cars Per Day Min.	Max.	Total Cycle Hours (Firing & Cooling) Min.	Max.	Max. Temperature of Pyrometric Cone	Type of F[...] Consumption/[...]
1.	G.E. Baltimore											
	No. 1 Allied (1955)	363'	6'4"	5'7"	7'3"	48	12	24	48	36	2200-2210^{o}F	nat. gas. 22[...]
	No. 2 Allied	362'6"	6'4"	5'7"	7'3"	49	12	24	49	98	cone $9\frac{1}{2}$ to	" " 22[...]
	No. 3 Allied (1941)	159'9"	6'4"	5'7"	7'3"	26	10	22	28	62	$11\frac{1}{2}$ (bottom)	" " 13[...]
	No. 4 Allied (1945)	162'6"	4'6"	5'	6'3"	25	10	18	33	60		" " 11[...]
	Note: Cars are exchangeable in kilns No's. 1, 2 and 3.											
2.	G.E. Schenectady											
	No. 1 Dressler(1934)	398'	5'8"	5'2"	7'9"	50	8	16	66	150	2300^{o}F 9-$10\frac{1}{2}$	City gas (5[...] 250,000 cu.f[...]
	No. 2 Dressler (1941)	283'	5'8"	5'2"	7'9"	35						
	Note: Both kilns dismantled. The No. 2 kiln purchased and rebuilt at Illinois Porcelain Plant in 1957.											
3.	Lapp - LeRoy											
	Harrop (1924)	381'10"	5'10"	5'8"	6'6"	57	16		56	112	2300^{o}F	Oil or nat.[...] 1150 gal o[...] 230,000 cu.[...]
	Allied	348'	5'10"	5'8"	6'6"	24	10		66		cone $10\frac{1}{4}$-$10\frac{1}{2}$	
4.	Ohio Brass Co., Barberton											
	Harrop	380'	4'4"	5'1"	7'9"	30	16		51		2310^{o}F	Nat. gas or[...] (stand-by)
	Dressler	220'	4'4"	5'1"	7'9"	28	12		56		cone 11-12	
	Allied (1955)	366'	4'4"	5'1"	7'9"	47	24		46			
	Note: All cars interchangeable. O.B. kilns have a narrower cross-section than G.E. (Baltimore) kilns.											

Length	Car Dimensions Width	Height	Length	No. of Cars	Cars Per Day Min.	Max.	Total Cycle Hours (Firing & Cooling) Min.	Max.	Max. Temperature of Pyrometric Cone	Consumption/24 Hrs.	Remarks
200'	3'8"	4'1"	6'2"	22	10		60		2260°F-2300°F	oil - 840 gallon	Kilns temp. also regularly checked by optical pyrometer. Only 2 burners each side - kiln for coffee pots and other specialties
200'	3'8"	4'1"	6'2"	30	16		49		cone 11-11½	oil	
150'	3'8"	4'1"	6'2"	23	16		49		"	oil	
120'	2'6"	3'0"	5'0"	22	16		49½		"	oil - 640 gallon	
Note: The Victor kilns are the shortest and smallest in cross-section in the industry. The firing costs are comparatively high.											
345'	5'4"	5'8"	7'9"	35	19		67		2300°F	nat.gas-139,600 cu.ft.	Best "W" kiln
411'	5'4"	5'8"	6'9"	60	10	16	90	150	Cone 10-11		
145'	5'4"	5'8"	6'9"	14	14		58			nat.gas-130,000 cu.ft.	"W" also has 5 periodic gas-fired Dressler kilns for large bushings
201'	3'3"	5'6"	6'0"	33	10		57		cone 11	oil - 630 gallon	rebuilt for gas firing, ware formerly fired in saggers.
308'	5'6"	5'0"	7'9"	39	14		68		2250°F	nat.gas-139,000 cu.ft.	
									cone 11		
123'	3'2"	3'6"	7'8"	15	18		90		2180°F	oil - 200 gal.	
148'	3'2"	3'6"	7'8"	19	10		51		cone 11	oil - 375 gal.	
360'	5'6"	6'10"	7'1"	49	19		62		cone 11-12	nat.gas-180,000 cu.ft.	
249'	5'6"	5'8"	7'1"	35	-		-			nat.gas-175,000 cu.ft.	
360'	4'0'	5'4"	6'0"	56	10		134		cone 11	nat.gas-155,000 cu.ft.	

	Insulator Manufacturer and Kiln Builder	Length	Car Dimensions Width	Height	Length	No. of Cars	Cars Per Day Min.	Max.	Total Cycle Hours (Firing & Cooling) Min.	Max.	Max. Temperature of Pyrometric Cone	Consumpti
5.	Victor Insulator, Victor, N.Y.											
	Allied No. 1	200'	3'8"	4'1"	6'2"	22	10		60		2260°F-2300°F	oil - 84
	Allied No. 2	200'	3'8"	4'1"	6'2"	30	16		49		cone 11-11½	oil
	Allied No. 3	150'	3'8"	4'1"	6'2"	23	16		49		"	oil
	*Dressler No. 4	120'	2'6"	3'0"	5'0"	22	16		49½		"	oil - 64
	*semi-muffle kiln	Note: The Victor kilns are the shortest and smallest in cross-section in the industry. The firing costs are comparatively high.										
6.	Westinghouse - Derry											
	Dressler	345'	5'4"	5'8"	7'9"	35	19		67		2300°F	nat.gas-13
	Harrop	411'	5'4"	5'8"	6'9"	60	10	16	90	150	Cone 10-11	
	Harrop	145'	5'4"	5'8"	6'9"	14	14		58			nat.gas-13
7.	Illinois Porcelain - Macomb											
	Harrop	201'	3'3"	5'6"	6'0"	33	10		57		cone 11	oil - 630
	Dressler	308'	5'6"	5'0"	7'9"	39	14		68		2250°F	nat.gas-13
											cone 11	cu
8.	Canadian Ohio Brass Niagara Falls											
	Dressler	123'	3'2"	3'6"	7'8"	15	18		90		2180°F	oil - 200
	2-Dressler's	148'	3'2"	3'6"	7'8"	19	10		51		cone 11	oil - 375
9.	R. Thomas Sons -Lisbon											
	Allied	360'	5'6"	6'10"	7'1"	49	19		62		cone 11-12	nat.gas-18
	Harrop	249'	5'6"	5'8"	7'1"	35	-		-			nat.gas-17
10.	Porcelain Products Parkersburg											
	Allied	360'	4'0'	5'4"	6'0"	56	10		134		cone 11	nat.gas-15

Observations on Tunnel Kilns - Table 5 - Kiln Data

Some of the tunnel kilns described in this tabulation are more than 30 years old. Most of the Harrop kilns have been rebuilt (by Allied) and where available, converted to natural gas firing.

Some other interesting information can be gathered from this tabulation. The earlier kilns were often more than 400 feet long. Today, the trend is toward shorter kilns and most of the insulator manufacturers have at least one longer and one shorter kiln as the latter can be fired to full capacity when the amount of business is reduced.

Recent Trends in Kiln Construction and Firing Rates

Looking over all the kilns that have been built for the electrical porcelain industry we find that:

a. They ranged in length from 120 to 420 feet, 33% were from 310 feet to 380 feet in length and another 30% between 200 feet and 280 feet. Only four kilns of more than 400 feet were built for the industry. The Baltimore No.1 and No. 2 kilns are 360 feet long, which are of average length.

b. Cross-section (setting width) from 3'2" to 6'4". More than 50% have a cross-section of 5'8" to 5'6". Baltimore kilns No. 1, 2 and 3 are 6'4" wide cars, the widest in the industry. This makes for good firing capacity, but requires also good car loading (open-setting) practice to obtain uniformity of heat distribution across the cars.

c. Firing Temperatures - Rate of Firing. The average maximum kiln temperature in American electrical porcelain kilns is 2200°F to 2250°F, pyrometric cone $9\frac{1}{2}$ to $11\frac{1}{2}$.

   The recent trend is to fire kiln as fast as the ware will stand, body adjustments have been made everywhere for faster firing, finer ground flint, low-carbon ball clays.

Chapter XIV - High Strength Porcelains

High Strength Porcelains Desirable

For more than sixty years and still today, clay-feldspar-flint porcelain, which might be termed "classical" porcelain, has been the principal ceramic construction material for high and low voltage insulators. For most of this application it has fully met dielectric and mechanical requirements.

There are, however, areas of application where higher strength porcelain is highly desirable and various attempts to develop special types of high strength porcelains have been made in past years.

It became soon evident that such improvement could only in replacing pottery flint in the body with other non-plastic materials, such as calcined kyanite (mullite), zircon, i.e. zirconium silicate or alumina.

Earlier Developments

As early as 1921, Schenectady ceramic engineers[1] experimented with electrical porcelain bodies, replacing part of flint with calcined alumina.

Alumina

In 1926 Fred M. Locke[2] obtained a patent for a ceramic insulator body consisting of 50% clay, 35% calcined alumina and 15% manganese dioxide to replace feldspar as the alkali flux, fired to cone 10. We have no record whether this body was actually used for high voltage insulators.

In Twell's and Locke's cases, undoubtedly the scarcity and the high price for calcined alumina at that time was the deterrent to further development.

Mullite Porcelain

Other flint substitutes tried at Baltimore and Schenectady ceramic laboratories were calcined kyanite (mullite) and sillimanite, both crystaline aluminum silicates. However, such highly refractory and rather inert refractory grains added little, if anything to higher strength when fired to regular porcelain kiln temperatures. In addition to this, the lower thermal expansion in such special bodies made it practically impossible to apply regular porcelain without losing more than 50% in mechanical strength.

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(1) R. Twells, Jour.Am.Cer. Soc.
(2) U.S. Patent 1,572,730, 2/9/26.

Of greater interest was the development of zircon porcelains as a war born ceramic insulating material. Originally developed as high frequency dielectrics in radio and radar devices, zircon porcelain soon was found a desirable material for some type of apparatus insulators where higher mechanical strength was essential.

Zircon Porcelain

Zircon porcelain may be manufactured by any of the conventional ceramic mixing and molding processes, including "dry mixing", extrusion and casting.

The Westinghouse Company at Derry still manufactures zircon porcelains, in limited quantities, including a line of hermetically (metal) sealed bushings for radar transformers. The high strength and thermal shock resistance and low-loss characteristics of zircon porcelains are here of great advantage.

Locke Zircon Porcelain

The Baltimore Ceramic Laboratory has been using one wet process and one casting body of the following composition. Both are fired to cone 10 in regular porcelain tunnel kilns.

Material	Wet Process Body	Casting Body
M&D Mississippi Ball Clay	14%	-
Royal Ball Clay	14	30%
Bentonite (Vol Clay)	2	-
"G" Milled Zircon	40	40
Caldium-Zirconium Silicate	30	30
	100%	100%

Special glazes were developed for these zircon bodies with compositions as follows:

	White	Brown
Potash Feldspar	27.9%	27.9%
Flint	29.8	20.5
China Clay	9.3	9.3
Ball Clay	9.3	9.3
Whiting	9.3	9.3
Zircon "G"	9.3	9.3
N.Y. Talc	2.8	2.8
Zinc Oxide	2.3	2.3
#7860 Brown Stain	-	9.3
	100.0%	100.0%

Zircon bodies, however, have certain disadvantages which precluded general adoption, such as for instance, the production of transmission line insulators. There are the appreciably higher raw material costs for the zircon fluxes. There is the considerably greater hardness and abrasiveness which makes zircon insulators difficult to grind, and the 50% higher fired density, and which would appreciably increase the weight of such insulators.

Alumina Porcelains

During the years from 1950 to 1955 ceramic engineers at Baltimore and Schenectady experimented with and developed a series of special high strength porcelains, containing from 20% to 50% finely ground calcined alumina.

A casting body, containing 20% calcined alumina, was developed in 1949 at the Schenectady ceramic laboratory for the production of porcelain donuts (synchroton tubes).

In 1951 ceramic engineers at Baltimore experimented with a wet-process body (No. 294) in which all the flint was replaced with calcined alumina. Finally, in 1955, after further exploration in this field, a series of high strength wet-process porcelain bodies, containing from 20% to 50% finely ground calcined alumina were developed. As shown in diagram, Figure 1, the fired mechanical strength is proportionally increased with an increase in alumina content. It was also found that the best all-around working properties, dried and fired shrinkage, was obtained with about 40% alumina addition.

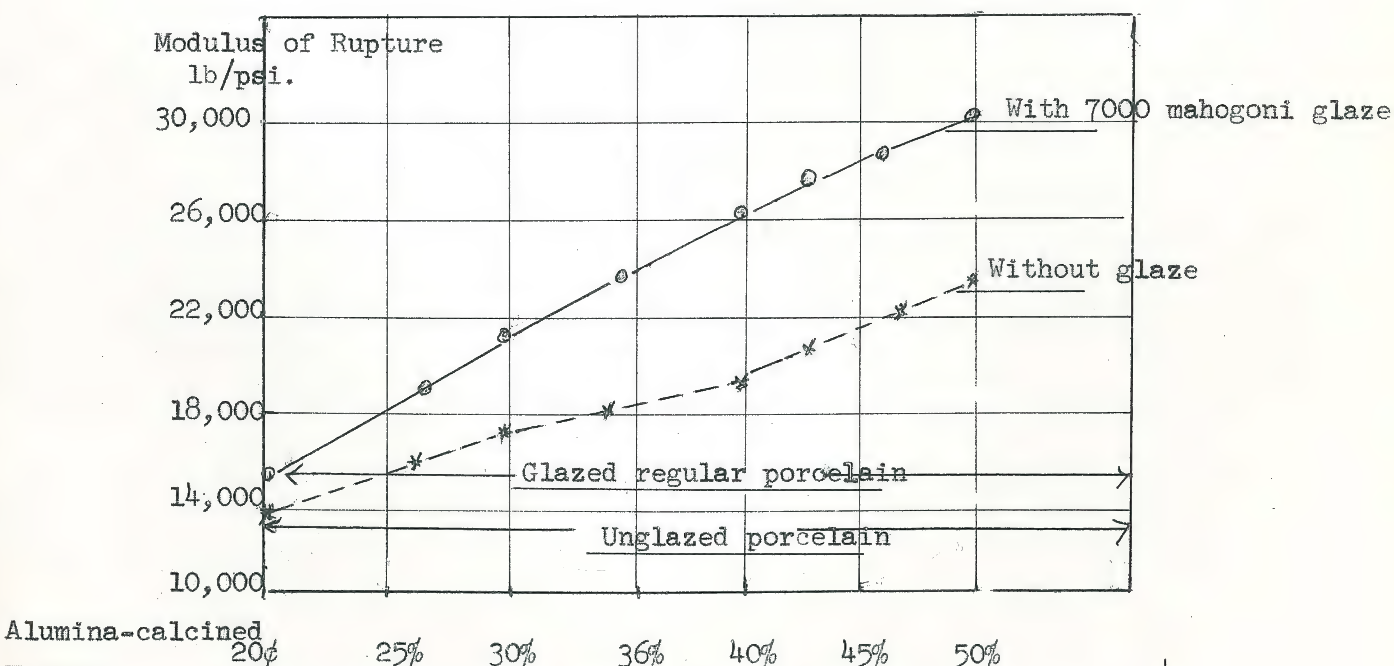


Fig 1. Effect of increasing alumina additions upon fired strength.

Table I. High Strength Bodies and Glazes

High Strength Porcelain and Glazes

Wet-Process No. 304 Body	
M&D Ball Clay	17.9%
Royal Ball Clay	13.0
Kamec Kaolin	4.6
Va. Feldspar	25.5
A-2 Alumina	39.0
	100.0%

Casting Body No. 304-C	
Bandy Ball Clay	9.5%
#817 Ball Clay	9.5
Eng. China Clay	15.0
Va. Feldspar	25.5
#2 N.Y. Talc	1.5
A-2 Alumina	39.0
	100.0%

Mahogany Glaze 7000B	
Feldspar	17.80%
Whiting	16.60
Ball Clay	13.70
China Clay	9.80
Flint	32.50
Iron Oxide	3.1
Manganese Oxide	6.5
	100.00%

Lt. Gray Glaze No. 2205	
Feldspar	17.96%
Whiting	16.70
Ball Clay	13.89
China Clay	9.81
Flint	32.91
Superpax	5.73
H-26 Gray Stain	3.0
	100.00%

Microstructural studies show a marked difference between high strength (alumina) porcelain and common electrical porcelain. In alumina bodies, no free quartz is present, the fired structure is more homogeneous and the crystalline particles considerably finer. Also, there is more crystallized mullite and less glass present, all these contributing to the much higher density and strength of these special porcelains. Chemical compositions of various porcelains are shown in Table II.

If we then compare the general chemical compositions and thermal properties of the special porcelains described in this chapter with that of the common type electrical porcelain, we obtain the following description:

Type	Non-Plastic Constituents	Plasticizing Constituents	Flux	Max. Safe Operating Temperature
Reg. H.V. Porcelain	Flint (SiO_2)	Clay ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$)	Alkali Feldspar ($KNaO \cdot Al_2O_3 \cdot 6SiO_2$)	150°C
Zircon Porcelain	Zircon ($ZrO_2 \cdot SiO_2$)	Clay - same as above	Alkaline-Earth Zirconium Silicates of CaO, Mgo or BaO	540°C
Alumina Porcelain	Calcined Alumina (Al_2O_3)	Clay - same as above	Alkali Feldspar ($KNaO \cdot Al_2O_3 \cdot 6SiO_2$)	150°C

TABLE II

CHEMICAL COMPOSITION OF FIRED PORCELAIN

MECHANICAL STRENGTH

	Clay-Feldspar-Flint Porcelains			Clay-Flux-Alumina Porcelains					
	Locke (a) 740-1	Japanese 1	Japanese 2 (b)	Locke (c) #304	Locke #308	Japanese 3 (d)	Japanese 4 (d)	Japanese 5 (d)	French 6 (e)
SiO_2	70.52%	70.10%	73.34%	40.42%	32.10%	26.60%	27.80%	29.60%	40.02%
Al_2O_3	22.19	25.70	21.44	53.05	62.90	54.20	52.50	50.50	54.20
Fe_2O_3	0.95	0.50	1.00	0.77	0.54	1.00	0.80	0.70	0.69
TiO_2	0.42	-	0.38	0.63	0.29	-	-	-	0.51
CaO	0.45	0.30	0.35	0.84	0.28	2.70	2.70	2.20	0.70
MgO	0.29	0.30	0.12	0.10	0.10	0.70	-	0.70	0.38
K_2O	4.06		1.65	3.17	2.94	0.70	1.10	1.30	1.42
Na_2O	1.23	3.75	1.39	0.75	0.85	0.30	0.50	0.50	2.20
B_2O_3	-	-	-	-	-	0.50	3.10	0.60	-
ZnO	-	-	-	-	-	-	0.70	-	-
BaO	-	-	-	-	-	3.00	-	-	-
SrO	-	-	-	-	-	-	-	2.80	-
PbO	-	-	-	-	-	10.40	10.90	11.10	-
	100.10%	100.65%	99.67%	100.06%	100.00%	100.10%	100.10%	100.10%	100.10%
Mechanical Strength									
Modulus of Rupture lb./psi									
Unglazed	11,000	13,370	not det.	18,000	22,400	28,730	25,600	24,890	
Glazed	15,000	-		25,000	possibly glazed specimens				

These Japanese porcelains are apparently experimental compositions - so far no alumina porcelain has yet been found in Japanese high voltage insulators examined at Baltimore

(a) Analysis by Sharp-Schurtz 11/26/56.
(b) Analysis made by Sharp-Schurtz of Japanese fog type insulator (suspension) Feb. 1957.
(c) Sharp-Schurtz Analysis 6/18/57.
(d) Data given in Journal American Ceramic Society, Japanese Experimental Bodies.
(e) Sharp-Schurtz Analysis 8/28/57 - Companie Electro Ceramique, Lourdes, France.

Table III Characteristics of Alumina, Zircon and Regular Wet-Process Porcelain

	Physical Properties	No. 304 Alumina	No. 702 Zircon	No. 740-1 Regular Porcelain
	Specific Gravity	2.77	3.75	2.38
	Density (lbs. per cubic inch)	0.103	0.136	0.086
	Hardness (Moh's scale) body	7.0	8.0	7.0
	Hardness (Moh's scale) glaze	6.5	6.8	6.5
	Water Absorption (%)	0	0	0
	Total Shrinkage, % dry basis	14.2	19.0	13.1
	Mechanical Properties			
1	Modulus of rupture, unglazed (lbs./in.^{2})	18,000	20,500	11,000
1	Modulus of rupture, glazed (lbs./in.^{2})	25,000	18,300	15,000
	Compressive strength (lbs./in.^{2})	75,000	65,000	50,000
	Tensile strength unglazed (lbs./in.^{2})	8,500	10,000	6,000
	Tensile strength glazed (lbs./in.^{2})	9,500	-	7,000
2	Impact strength unglazed (ft.lbs.)	1.0	-	0.7
2	Impact strength glazed (ft.lbs.)	1.2	-	0.8
	Modulus of elasticity (lbs./in.^{2})	14×10^6	-	10×10^6
2	Impact 3/4" bars -3" span unglazed - 7.2 in./lb.	-	-	3.8
	Electrical Properties			
3	Dielectric Strength (volts/mil)	230	210	200
	Power factor	0.0063	0.0010	0.0085
4	Loss factory	0.0403	0.0080	0.0476
	A.W.S. L - classification	L-2	L-5	L-2
	Dielectric constant (k)	6.4	8.10	5.6
5	Volume resistivity (megohm/in.^{3})	4×10^6	4×10^5	4×10^6
6	t_e value (^oC)	300	540	300
	Thermal Properties			
	Resistance to thermal shock	good	superior	good
	Linear Coefficient of Thermal expansion x 10^6 (00-600^oC)	6.8	4.3	5.94
	Thermal Conductivity (cal/cm^2) (cm/sec/^oC)	0.0047	0.0052	0.0034

1. Test bars 0.75" diameter, span 5".
2. Standard Charpy Impact Test - test bars 0.75" diameter, span 4".
3. Specimens approximately 250 mils thick.
4. After soaking in distilled water for 48 hours at room temperature tested at 1.0 mc per AWS C-75-1 - JAN - I-10.
5. At 10 volts per mil and 77^{o}F.
6. Temperature at which centimeter cube has resistance of 1 megohm.

An outstanding characteristic of zircon porcelain is its high strength at elevated temperatures, as shown in Figure 2.

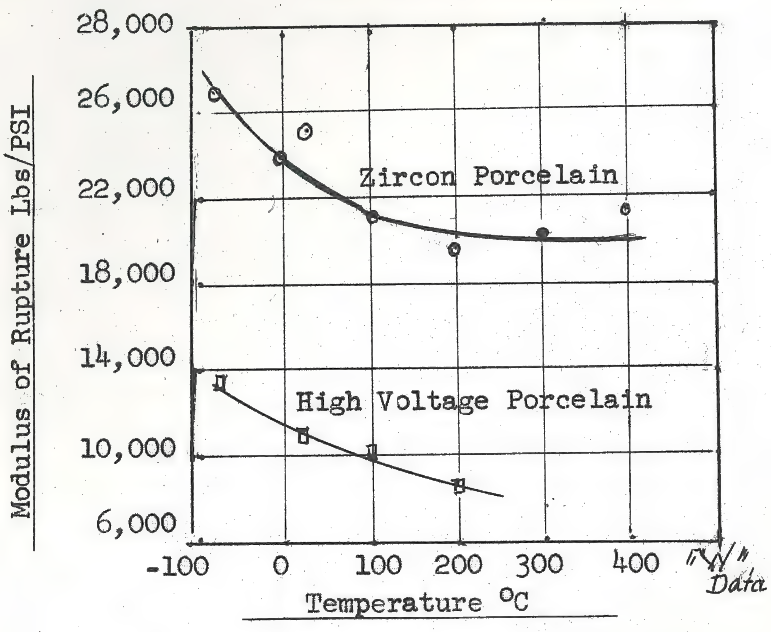


Figure 2. Effect of Temperature Upon the Modulus of Rupture of Zircon & High Voltage Porcelains

Comparative data of the mechanical, dielectric and other physical properties of the three types of electrical porcelain is presented in Table III.

Whereas zircon porcelain, for reasons explained in this chapter remains now to be utilized only within a very limited field of application, alumina porcelain insulators will undoubtedly be produced in future in every increasing quantities. At the present time, the ocst of the No. 304 alumina body is $3.60/100 lb. against that of $1.50/100 lb. for the No. 740 regular clay-feldspar-flint body. But with ever increasing volume of aluminum oxide production and expected reduced costs, it appears quite possible that some time in the future practically all types of high voltage porcelain insulators will be made from alumina bodies.

Chapter XV. - Surface Conditioning for Insulator Assembly

In insulators which consist of several parts or those which are assembled with hardware, it is customary to unite these by means of Portland cement.

Surface Preparation for Cement Grip

The surface of the insulators so to be connected may be grooved, scored, knurled or otherwise roughened to obtain a high strength anchorage for the cement.

The methods applied to prepare such cementing surfaces, have, over the years of insulator manufacture, undergone various interesting changes and developments, which are discussed in this chapter.

Earlier Methods

Up to about 1916 insulator parts to be joined with cement were either grooved or knurled, the latter usually being in a "fish skin" pattern. An example of a two-part pintype insulator is shown in Figure 1.

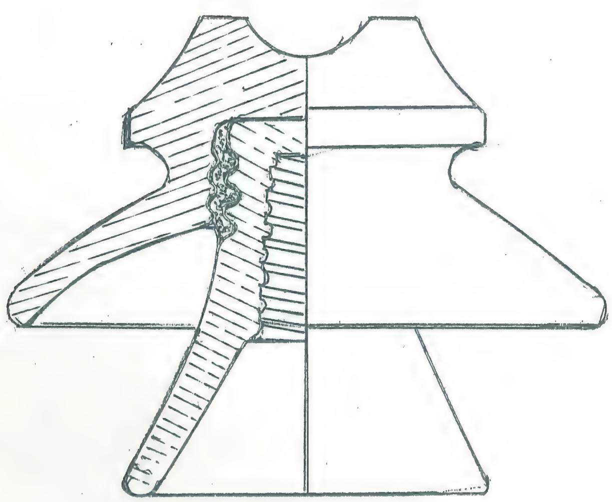
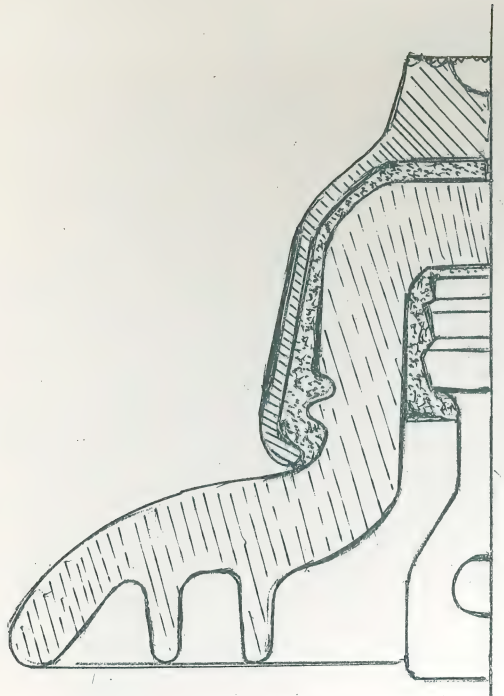


Figure 1. Ohio Brass Two Piece Cemented Post Insulator Grooved Top and Bottom Section (1916)



An older type of
Locke suspension
type insulator
with grooved head
is shown in Figure 2.

Locke-Victor
No. 7500
1920.

Some of the German suspension insulators are still made with this grooved head. However, no cement is used anymore in German pin assambly.

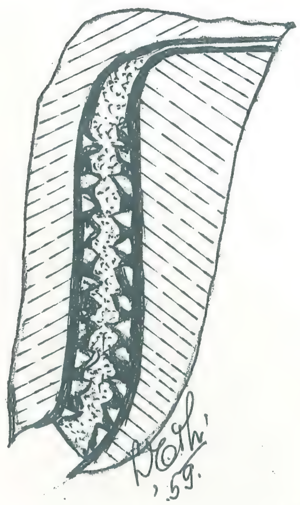
Large cast sectional transformer bushings manufactured at the Schenectady Porcelain Plant were also supplied with circular grooves, as shown in photograph, Figure 3.

Fig. 3. Schenectady Cast sectional bushings.
Before adoption of present sand belts.

However, neither such grooving, knurling or otherwise roughening of the surface proved in the long run, satisfactory from the standpoint of high insulator strength. As a matter of fact, instances occurred where, due to mechanical shock, grooved demented porcelain section would break off, whereas knurled or cross-hatched would, in firing, develop infinitesimal cracks which cut into the porcelain surface and resulted in considerable weakness at the cement joints of the insulators. Such fine cracks may heal up by applying a glaze over the scored surface. But, here again, Portland cment does not adhere readily to a glazed surface and, therefore, this glaze coating, which usually increases the strength of porcelain, did not help much toward a strong cementing grip.

Knurling, Grooving Scoring Lowers Strength of Porcelain

Finally, a solution was found in the development of satisfactory and strong cementing surface in the form of a band of granular porcelain particles, known in the industry as "sand" [1]. These sand particles consisted of carefully sized fired porcelain which were fused to the insulator body by the porcelain glaze. Today, every American, two British and a Japanese insulator manufacturer has adopted such "sand bands". Sections of a multipart pintype insulator, showing this sand and the cement connecting these are shown in sketch, Figure 4.



For several years (unfired) i.e. raw porcelain sand was applied, as recommended in the Ohio Brass patent. It was thought that the raw porcelain sand would shrink with the body and, since both have the same coefficient of expansion and contraction, this would give the best, strain-free combination.

Figure 4. Porcelain Sections Locked Together With Portland Cement. A Coating of Asphalt is Usually Sprayed Over Banded Area Before Cementing

(1) Ohio Brass, Pat. 1,284,975, 11/19/18

However, such unfired granular particles are soft and fragile and, therefore, pre-fired porcelain sand was adopted at the G.E. Schenectady and Baltimore insulator plants. By glazing over this sand (2) a further increase in the strength in these cement grip areas was obtained. Several insulator manufacturers (Parkersburg, the British Taylor-Tunnicliff and Porcelain & Steatite Companies, and a Japanese Company) use such prefired porcelain sand. It has also been recently reported that German porcelain manufacturers have adopted crushed porcelain sand for supplying a cement grip to insulators.

Prefired Porcelain Sand

In 1940 Baltimore ceramic engineers experimented with various sand compositions. It was discovered that by using a sand material of substantially lower thermal expansion than that of the porcelain and in combination with the compression glaze a higher strength of the insulators was obtained(3).

In a similar development by the Lapp Company(4) a low expansion sand was adopted for their line insulators. The ceramic composition of the Baltimore and Lapp sand is shown in Table I.

Type of Sand	Ceramic Composition	Fired Composition	Thermal Expansion	Flexural Strength* Glazed and Sanded Rods
Baltimore Raw Sand	Ball Clay 95% Whiting 5%	Mullite & Cordierite	3.9×10^{-6}	15,000 lb/psi
Lapp's Best Prefired Sand	Clay 30-50 Beryl 65-40 Feldspar 5-10	Low Expansion Beryl Porcelain	3.4×10^{-6}	15,300 lb/psi

*Applied to Baltimore 740-1 Wet-Process Body

(2) Locke Patent 1,784,392, 6/3/42
(3) Locke Patent 2,287,331 , 6/3/42
(4) Lapp Patent - 2,337,691, 12/28/43

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The Lapp beryl porcelain sand was prepared by the writer, also low expansion zircon porcelain sand was tested by him on Baltimore wet-process porcelain[5]. Zircon porcelain (thermal expansion 4.3×10^{-6}) gives also a very strong "sand".

Lapp vs. G.E. Baltimore Sand

As shown by data presented in Table I, the prefired Lapp beryl porcelain sand did not produce a mechanically stronger body-glaze-sand combination than the unfired Baltimore sand. A cordierite sand also mentioned in Lapps patent proved to be of lower strength.

It should be noted here, that use of beryl in electrical porcelain was patented by G. E. Schenectady Porcelain Plant in 1923 (R. Twells).

Other Users of Baltimore Sand Composition

The raw Baltimore ball clay is less expensive, as no extra firing cost is involved. Also, the unfired off-size Baltimore sand body material can be reclaimed and reconditioned by remixing and screening. The Ohio Brass Company and, by all indications, the Pinco Insulator Company use Baltimore raw ball clay sand.

No glaze is applied over the Baltimore sand on suspension, fog type and multi-part pintype insulators. However, glaze over the sand belts is applied on most apparatus bushings which are shipped outside for assembly. The sanded areas are thereby strengthened against damage in transit and handling.

Of equal importance as compression sand and compression glaze is the temporary binder that must be added to the glaze to hold the sand particles up to the time the insulator enters the kiln.

Temporary Glaze Binders

Considerable firing losses in the form of circular cracks at the edge of the sand belt on suspension insulators was encountered in 1951 by the use of LePage's fish glue. In earlier years corn syrup was used as a temporary binder and this material is still used at the Illinois Porcelain Company and Parkersburg Porcelain Company. However, it has been shown that these temporary binders are very critical and spoil easy by fermentation.

---

(5) Investigation of Ceramic Bodies for Cement Grip (Sand) L.E. Thiess, Technical Report LK-151-CR, 6/17/57

In 1950 the writer introduced at Schenectady a water soluble synthetic binder (acrylic polymer) which proved to be very satisfactory. In 1952 this binder was adopted here at Baltimore, with the result that since then head cracks on sand bands have virtually disappeared.

Recently, the Rosenthal (German) Factory obtained a patent for the use of a water soluble silicon-resin emulsion for the temporary binding of porcelain sand on high voltage insulators. This material likewise will not spoil with aging of the sanding glaze.

CHAPTER XVI - Manufacturing Defects and Losses - Their Cause and Cure

In none of the little existing technical literature on electrical porcelain or other ceramic Whitewares can one find a comprehensive discussion of manufacturing losses, their causes and cures.

And yet, from time immemorial producers of such wares have struggled with the problem of unfired and fired losses, both which contribute so much to high manufacturing costs, poor quality ware and loss of profits.

The attached photograph shows an accumulation of scrapped fired insulators of almost every type and description made at the Baltimore Plant. It may perhaps serve well to emphasize the problem of losses and prove the old adage that "Seeing is Believing".

Manufacturing losss data are now almost universally obtained by statistic methods and the up and downward trend presented in diagrams such as shown in Figures 1 and 2.

Manufacturing losses may also be expressed in actual dollar values, such as in the following for Baltimore scrapped unfired and fired ware for 1956 and 1958 operations:

1956 - output 7,3 mil. - losses 1,7 mil.(23%)

1958 - output 6,0 mil. - losses 1,1 mil. (18%)

For some obvious reasons, competitor insulator manufacturers will rarely, if ever, discuss or reveal such loss figures and, therefore, it is impossible to have a true comparison between theirs and Baltimore's losses. However, some, more of less accurate, but nevertheless interesting information of losses in various types of insulators have been obtained from our plant visitations or from discussion of this subject with competitors visiting our Baltimore plant.

Losses - Baltimore and Outside Insulator Manufacturers

Here are some examples and comparisons:

Illinois Porcelain Co. reported 15% loss (making to include firing) for suspension insulators. Baltimore's total losses are 11.5% for the same type of ware.

Ohio Brass's firing losses for suspension insulators are reported to be 5% or less; Baltimore's firing losses for suspension insulators are between 4-7%. The O.B. loss for smaller apparatus porcelains is given as 20% - Baltimore's losses are about the same for this type of ware.

Lapp is reported to have "average" losses from 9-10%, i.e. they make 110 pieces to ship 100 pieces of ware. Such "average" loss statements have very little value and are even quite often misleading, because, as already shown in diagrams Figures 1 and 2, unfired and fired losses vary considerably for each insulator type manufactured.

What are the nature of losses in insulator manufacture, i.e. scrapped defective unfired and fired ware?

Type of Loss and Classification

Looking on a "Dry Ware Inspection Report" we find the following classifications: Cracked - Slugs - Folds - Burned - Damaged (bumped) - Warped - Chipped - Poor Finish and Careless Handling.

"Fired Loss Forms" contain the following classification: Cracked - Chipped - Careless Handling (bumped) - Rubbed Glaze - Foreign Substance (kiln dirt) - Laminated - Warped - Off Dimension - Bloated - Pinspots and Glaze Crawl.

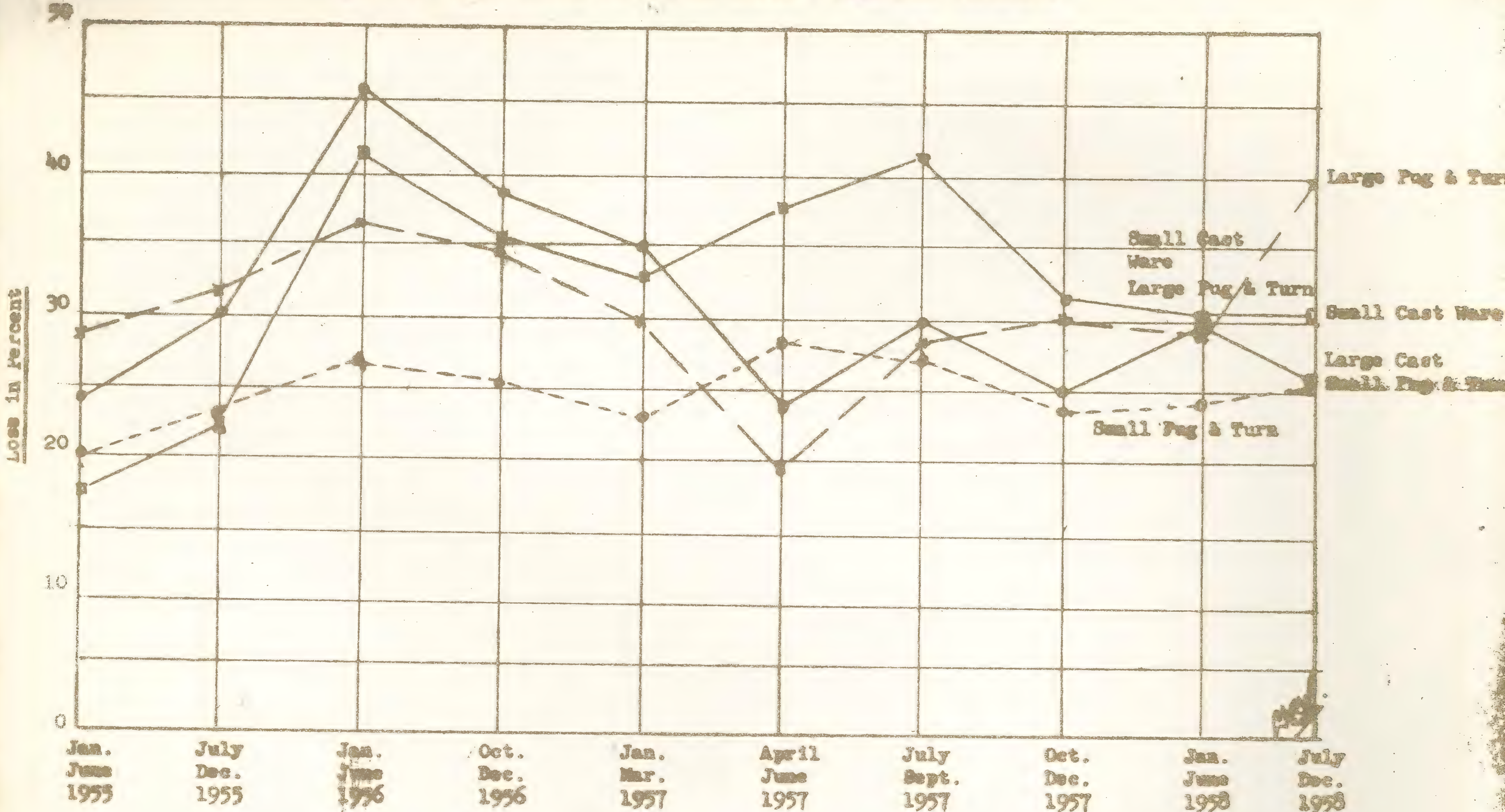
Whereas much of the unfired ware is salvaged as "body scrap" addition to the virgin body blungers, or as reground powder in the muller-type mixers, most rejected fired ware is a total loss.

In analyzing these losses, there are some, as for example those listed as careless handling, poor finishing (workmanship), chipped, etc., that belong in the area of proper training, instruction and supervision of factory operators. No further discussion on these will be given here.

There are, however, areas in this loss picture which are concerned more with technical aspects and which require a study of the processes involved, with trouble shooting and experimental work to find a solution for solving such loss problems.

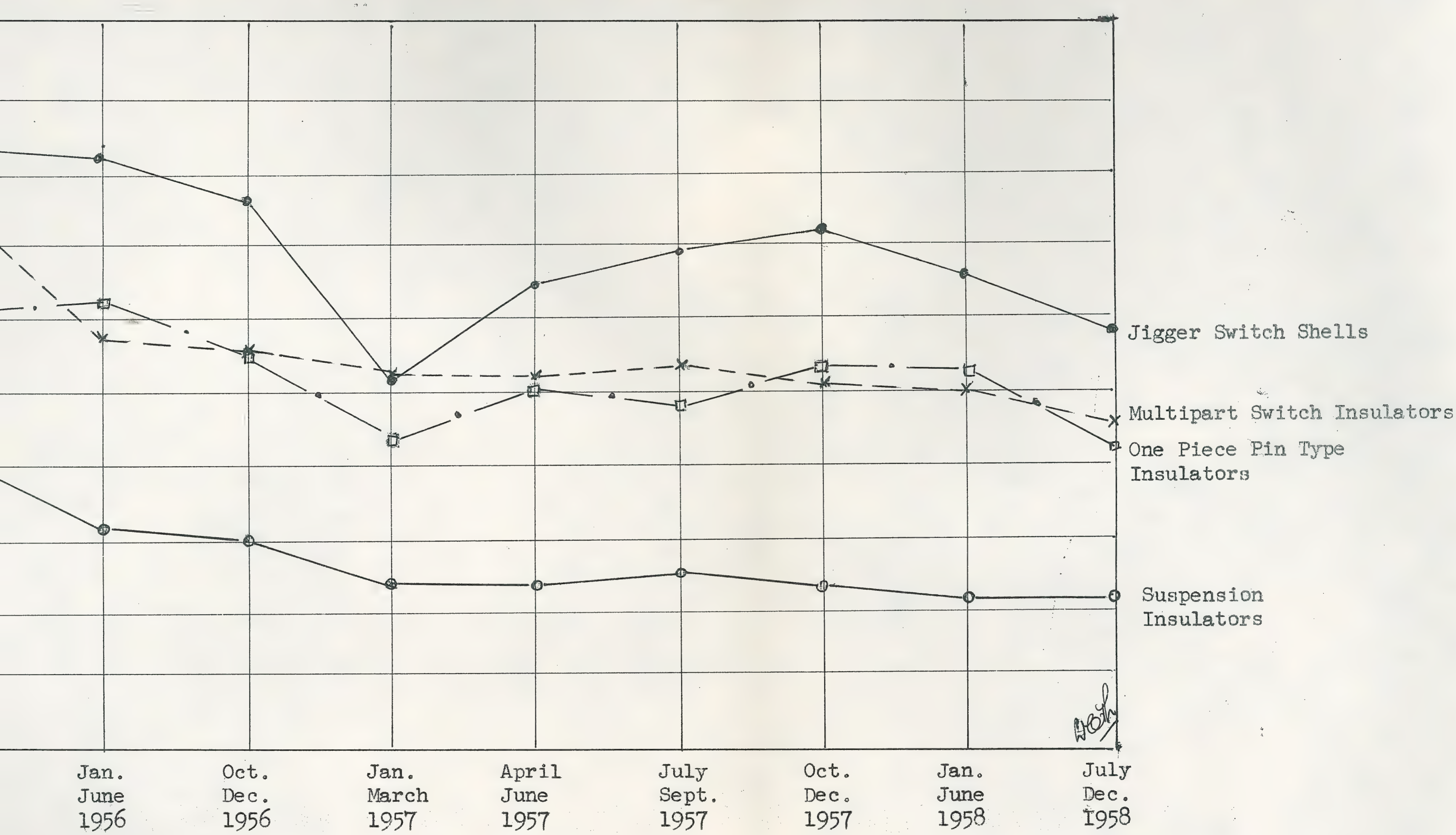
It has long been recognized in our porcelain industry that our difficulties have compound origins and we have to try to deal with them one by one.

Figure 2. Total Making And Firing Losses - Apparatus Porcelain



		Unfired	Fired Scrap	Reclaimable
1958 Average Percent Process Losses	Large Pug & Turn	15.7%	13.7%	8.2%
	Small Cast Ware	14.4	14.8	22.7
	Large Cast Ware	6.4	19.0	11.9
	Small Pug & Turn Insulators	13.0	12.4	14.1

Figure 1. Total Making and Firing Losses - Line Porcelains



		Unfired	Fired Scrap	Reclaimable
)	Jiggered Ware	19.4%	13.4%	13.8
Percent)	Multipart Switch Insulators	15.0	9.1	13.5
s)	One Piece Switch Insulators	16.2	7.4	8.6
)	Suspension Insulators	6.6	5.9	3.5

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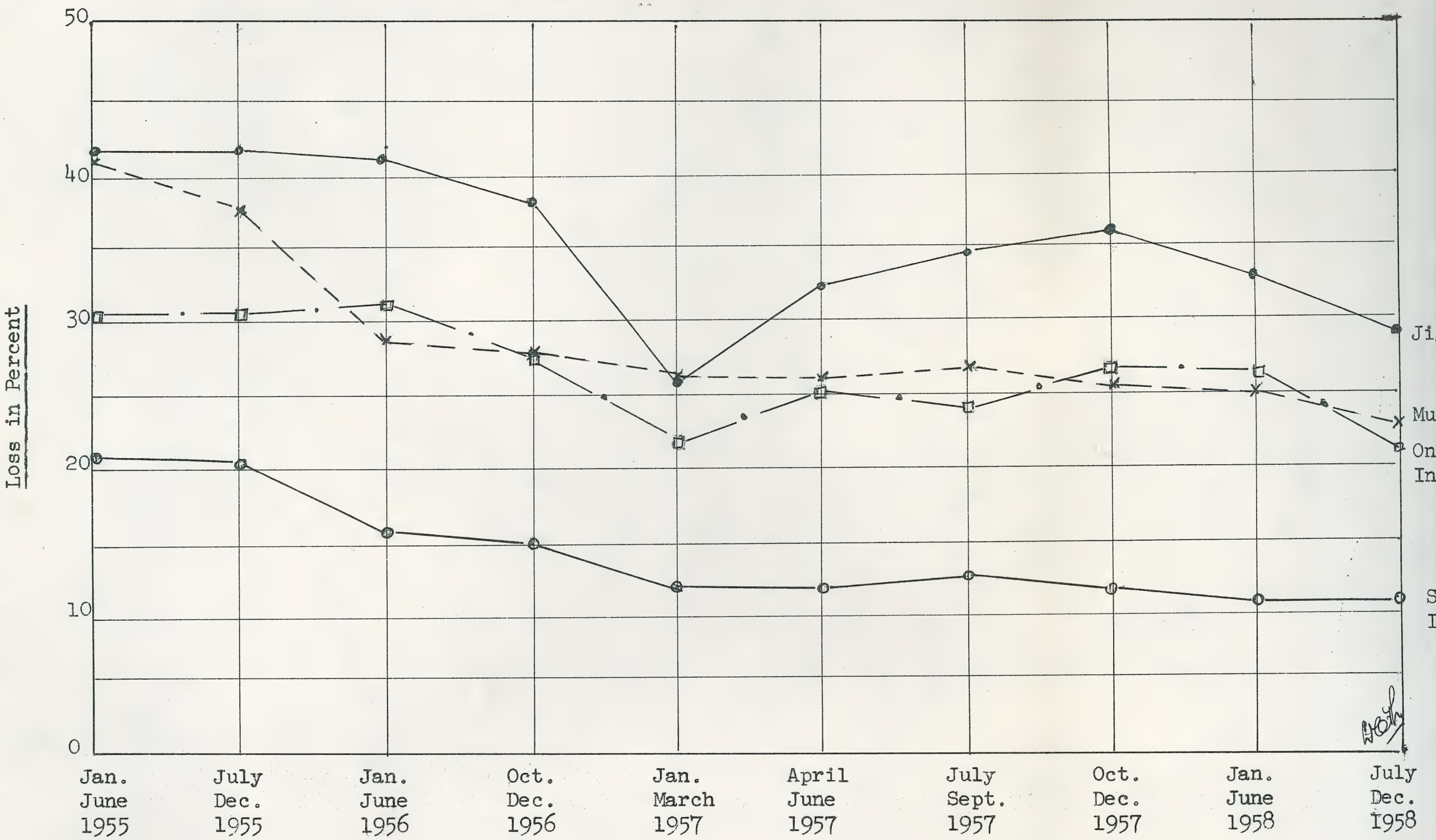

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One Piece Switch Insulators	16.2	7.4	8.6
Suspension Insulators	6.6	5.9	3.5

As has been shown in Figures 1 and 2, losses are different for different types of insulators, even the same insulator produced by different methods may shown a higher or lower loss.

Loss figures, as plotted in these diagrams, give no clue of the nature and causes of such losses. To obtain this information we devised a different graphic presentation which, for each type of insulator, gives a complete and comprehensive loss picture.

In these following circular graphs the areas and the nature of defects are shown which contribute the most to the total percentage loss in each piece. The next natural step is to study the cause and possible cure of these defects.

For example, Figures 2 and 3 show two large production, low loss items and the reason for rejection at the Dry Inspection Station (automatic glazing machine).

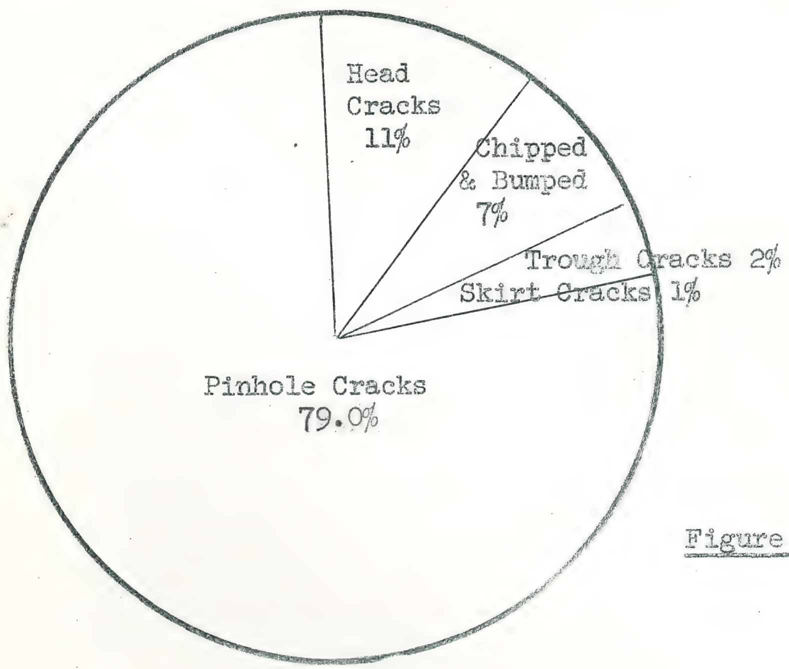


Figure 2

1840A - Average Dry Loss
Jan. - Mar. 1959 2.5%
(Single days 4-9%)

The loss in 1840A consisted almost all of pinhole cracks, very few head cracks.

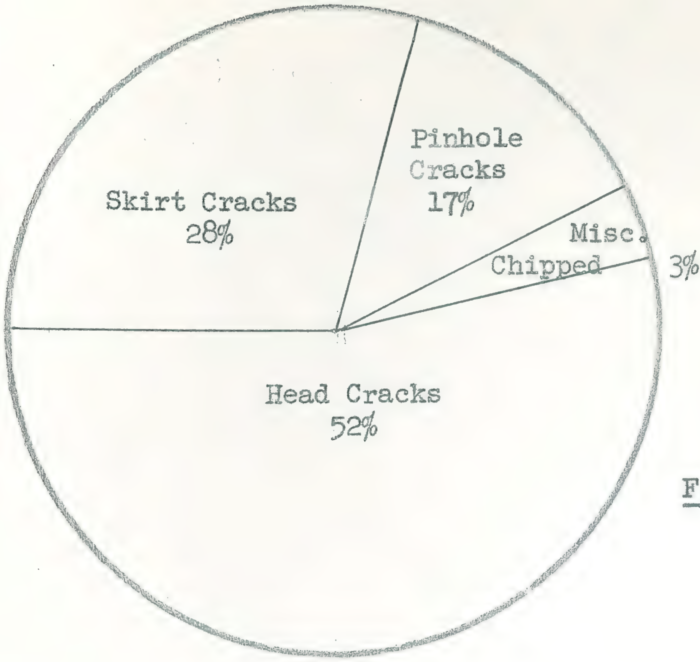


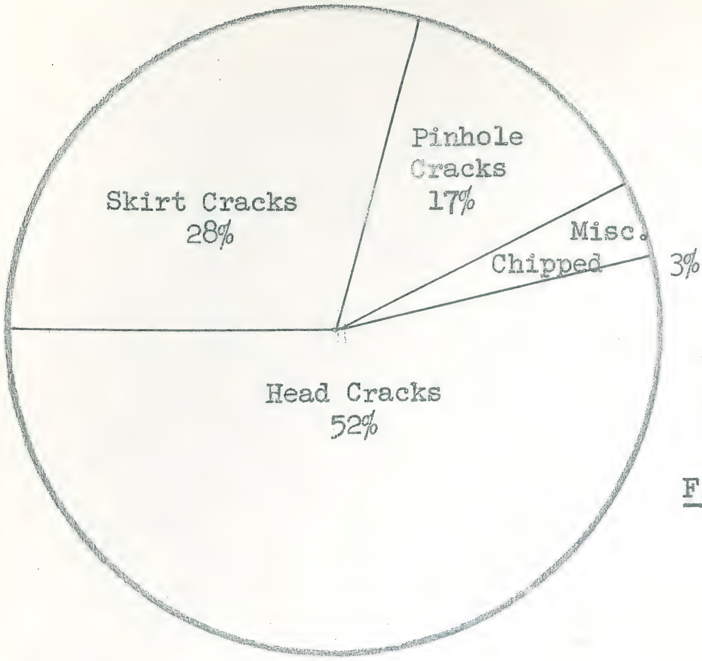
Figure 3

79004 - 6" Suspension Insulator
Average Dry Loss
Jan. - Mar. 1959 4%
High Single Day 19.6%

In No. 79004 insulators the situation is reversed with head cracks being the largest contributor.

Pinhole cracks in suspension insulators are usually caused by:
(a) cold plunger - slow die release (suction)
(b) wrong lubrication mixture (oil)
(c) plugged (spaghetti) plunger (must be replaced and cleaned every shift.
(d) clay with too soft consistency or clay too hard.

The higher losses in No. 79004 6" suspension insulators are contributed to the fact that the blanks pugged on single nozzle pugmills, are usually pugged hours, even one day before, resulting in partly stiffened and non-uniform blanks. The clay for 1840A 10" suspension insulators is pugged from a double die, excluding laminations and is used up as fast as pugged, insuring uniform consistency.



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Insulators made by jiggering methods have always been a comparatively high loss item. Jiggering is a manual operation and good results depend to a large extent upon the skill and care of the operators. It has been mentioned as one of the causes of high losses of this ware that jiggermen are allowed to make too many pieces rather than a number of good pieces per shift. Whatever the reasons may have been, investigations have been made in past years whenever the losses in these insulators increased over the amount considered "normal losses".

Jiggering

Losses

Average "Dry Inspection Losses" (unfired ware) in 1958 for all jiggered insulators were 19.4%. The firing losses were 13.4% (scrap) and the "reclaim" - repaired and refired losses were 13.9%.

In order to show the nature of defects and the reason for rejection of jiggered ware, a loss analysis was made of switch shells No. 79047.

The results are presented in diagram Figures 4 and 5.

Of the unfired loss, 45% consisted of trough cracks, i.e. in the corrugations. The majority of the losses in the fired shells consisted in small cracks on the side or top of the head, some cracks inside the head which were not visible at the Glaze Inspection Station. Internal flaws or folds, also not visible either before or after firing, contribute to puncture loss in the high frequency test.

A discussion of the causes and cure of these losses will follow under the heading "Jiggering Losses" in this chapter.

Breakdown of Unfired and Fired
Switch Shell Losses.

Drg. 79047

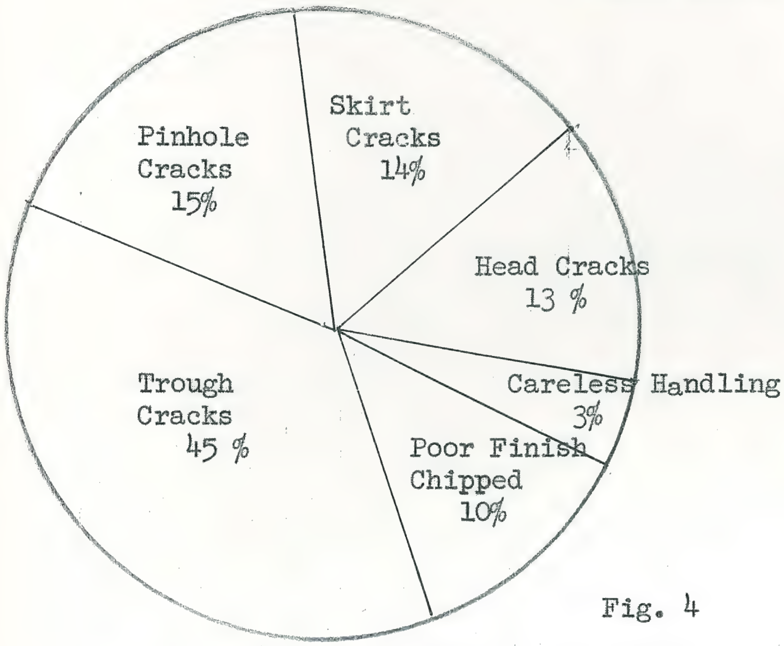


Fig. 4

Loss before Firing (Glaze Inspection)
Jan.- March 1959 13.4 %

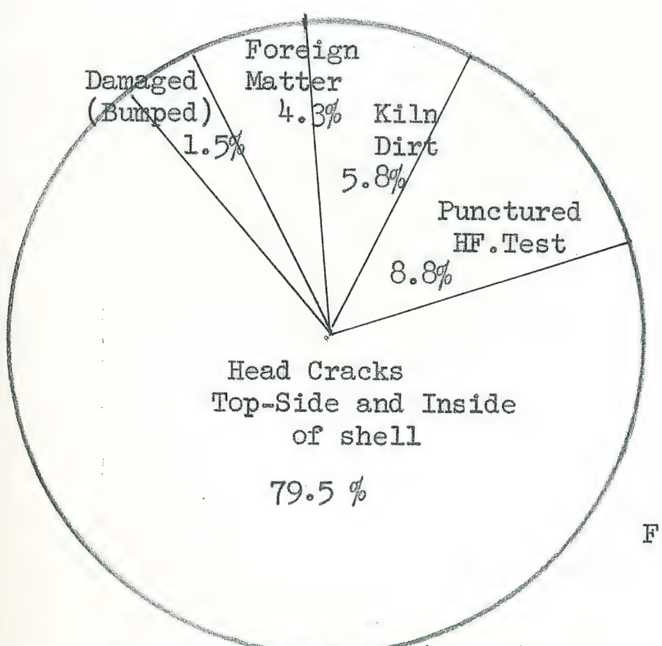


Fig. 5

Loss after Firing (Scrap)

Jan-March 1959 26.0%

Switch Shells
Cause for
Rejection

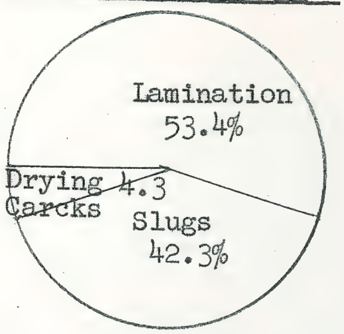
Dry and Fired
Losses

Manufacturing Losses for Apparatus Porcelains consist of a variety of defects somewhat different from that encountered in Line Insulators. Average Losses in 1958 for large pugged bushings were 27.5 percent and for small pugged bushings 23.7 percent.

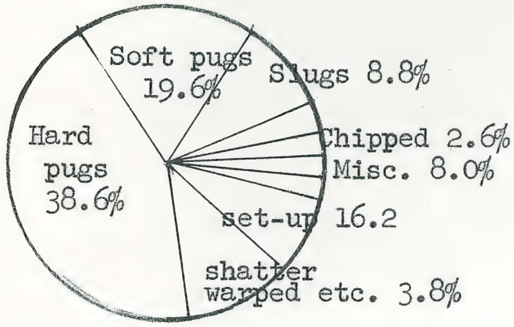
In 1953 an extensive analysis of manufacturing losses were made of apparatus porcelains and several thousands of bushings were examined for defects and various causes for rejection. (January to April 1953)

The results of this analysis is presented as follows:

Breakdown of Losses.



Hard Pugged Bushings



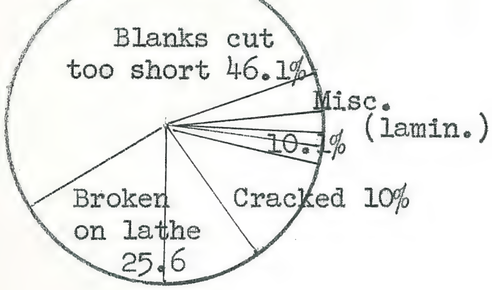
Green Finishing

- Total bushings rejected at this station 718 pieces. Hard and soft pugs account for the majority loss.

Lathe turning.

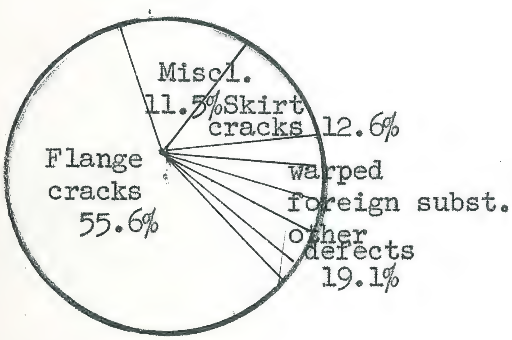
The combined nature of such losses is here clearly demonstrated. Poorly pugged blanks with laminations and slugs are the causefor losses in turning and firing.

Slugs in pugged blanks are caused by not removing hardned lumps in the pugmill(vacuum chamber)before starting extruding the pieces.



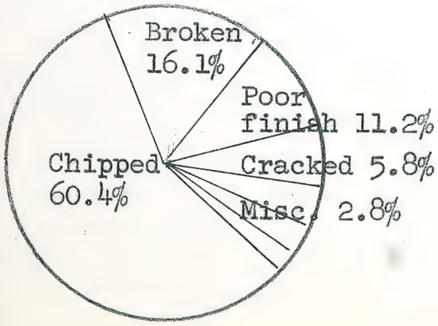
Dry Finishing

308 pieces rejected at this operation. 46.1% No. 92532 were cut too short on pugmill. Carless workmanship.



Dry Inspection before Glazing

10,475 rejected ,high loss due to cracks on flanges of insulators.



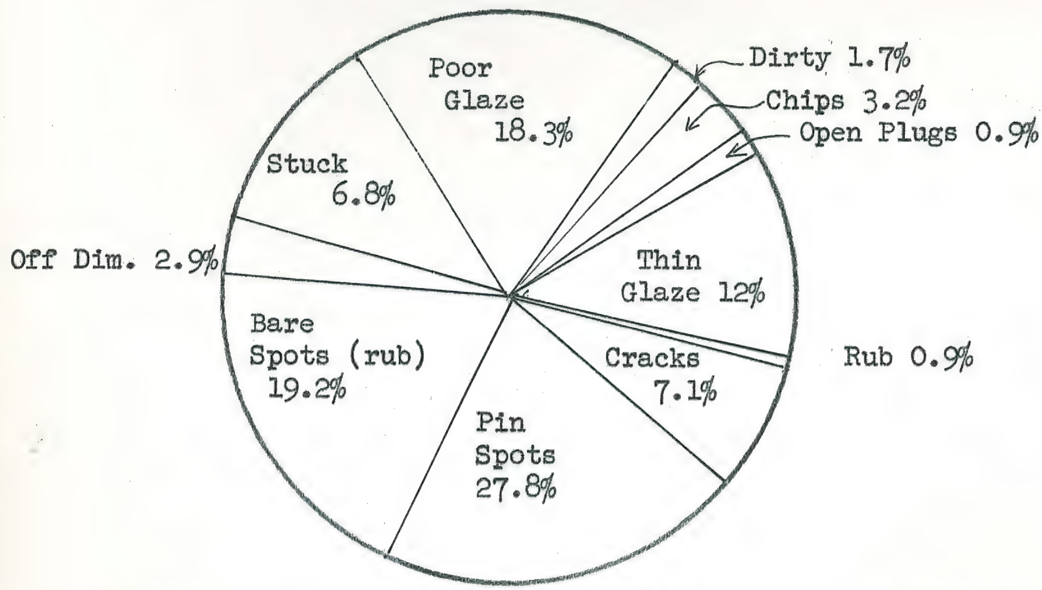
Glaze Department

1078 pieces rejected-high loss due to chipped and broken pieces, mostly due to careless handling.

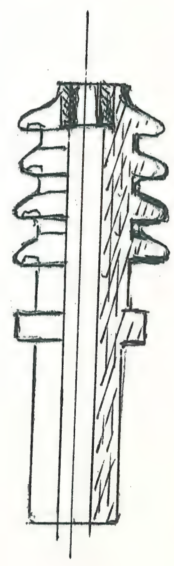
Glaze defects is another factor contributing substantially to firing losses. Although an appreciable amount of the rejected ware is salvaged by glaze touch-up and refiring, the rehandling and refiring are items that add considerably to manufacturing costs.

A typical example of a bushing rejected by the Inspection Department for various glaze defects is given. The breakdown of the firing loss for this bushing (No. 479B360) was obtained in a loss investigation in 1955. To this day of writing, similar glaze defects occur, although pinspots found more on glaze dipped ware (27.8% in this case here) are considerably reduced by spraying.

<u>Glaze Defects</u>



However, the application of glazes by spraying, either by hand operation or on the automatic (Binks) glazing machine, can result in unsatisfactory coating, such as "crawling", either by applying an excessive layer or by spraying over dirty (dusty) surfaces. The unfired glaze thickness should not exceed 12 mils.



Crawling was reported on recently glazed and unfired bushings (No. 9240654, 4/20/59) with 132 pieces out of 423 pieces inspected. A check on the glaze thickness on the automatic glazing machine could have avoided this defect.

How To Control Losses

Having, in the foregoing, described the characteristics of manufacturing losses and by statistical and graphic presentation the question now arises, how can these losses be reduced or kept under control?

As a general answer, there are some basic requirements that must be met, namely,

a. Practice a comprehensive and continuous raw material control, study and adopt any new information and new test methods available from research in this field.

b. Provide detailed manufacturing instructions for all processes and operations which, after found workable and approved on the basis of best know-how, should be observed without deviation.

c. Train and instruct operators properly and insist upon good workmanship. Operators must fully understand what factors lead to manufacturing losses in their respective working area.

d. Study and discuss new insulator with designers and experienced manufacturing people before the start of manufacturing. All too often, in the past, new jobs have been accepted which proved to be later high loss items and changes in design, tools, even methods of manufacturing became necessary, contributing to extra costs.

   The Locke booklet "How to Design Apparatus Porcelain" provides a good guide for the designer of porcelain insulators. It should give him also an understanding of the limitations that are inherent in ceramic processes. A copy of this booklet is attached to this "Handbook".

e. Conduct periodic "Waste and Spoilage Meetings" with manufacturing supervisors and ceramic engineers. At such meetings, which proved very successful in controlling losses at the former Schenectady Porcelain Plant, samples of defective insulators were displayed and ways and means discussed and recorded to prevent periodic recurrence of the same type of losses. The Baltimore Plant might well profit by such "Waste and Spoilage Meetings".

Many solutions for eliminating losses in various types of ware is simply applying common sense. Others call for a more detailed study, observation and experience.

Of the many contributing factors, causes and cures, only the most pertinent can be listed here, each one under its respective heading. Increased mechanization in our line of work leads some easily to a belief that "things take care of themselves". But as much as it is desirable to develop automatic production,methods and machinery, one cannot mechanize the "human side" in this clay working business and many operations still require experience, good judgement and care on the part of the operators.

In the following some of the most dangerous loss areas are discussed.

Body Preparation - Controls

The slip is chemically treated with aluminum chloride which increases the rate of filterpressing and prevents segregation in the filter cakes. An excess of this chemically destroys the plastic cohesion of the body, making the body "short" and produce cracks right after hot-press molding or during drying. The proper amount of aluminum chloride addition has been carefully established and specified in operating instructions, the addition of an excess is simply the results of carelessness.

Foreign matter (lignite from ball clays) can be introduced by a break in the lawns - the result is holes (blebs) in the fired body, pinholes in the glaze.

Pug Mill Operations

The pugging operation is one of the most serious sources of losses unless carefully controlled. Hard and soft filter cakes should never be fed in the mill. The amount of water in the body is the lubricant - the softer clay travels faster than hard clay - laminations in the pugged blanks is the result. Blanks for insulators of difficult design are better pugged twice - resulting in less losses.

The vacuum must be held within the specified range, the shredder blades should be checked often and the clearance between the blades not be more than 1/8".

Before pugging, all hardened clay should be removed in the mill, otherwise "slugs" will be included in the blanks. Applied common sense? Sure enough!

Jiggering

One of the difficulties inherent in jiggering large shells is that in most cases the plastic clay is not solidly packed in the bottom of the mold (head section of the shell). The operator now uses a mallet to pound and spread the clay inside the mold. The difficulty of uneven density in the shell has long been realized and (patented) methods suggested consisted of vibrating the molds containing the clay or using an automatic tamper to pack the clay in the mold (1), (2). In 1956 the Baltimore Ceramic Engineering Section conducted experiments with an electric vibrating tamper with promising results. This eliminated folds, voids and weakness in the head section. Adoption of a vibrating tamper prior to jiggering the shells is still recommended.

Ultrasonic (non-destructive) testing detected such flaws in jiggered, green finished shells - a well worthwhile method to reduce losses. Immersion method gives best results (3).

Other quite common causes for defects in jiggered ware (see page 178) are: pugged blanks too stiff - forces jiggerman to use too much pounding in mold, body stretched and ruptured - too much water required to form piece - trough cracks result. Empty jiggered pieces from mold too early, distorting piece, trough cracks. Finish soft pieces on humps - opens up clay in head section - small cracks formed in firing on side or inside head, rejection at "Fired Inspection Section" or breakdown in electric H.F. testing. Jigger profiles should be smooth and free from sharp edges to prevent tearing the clay.

Apparatus Porcelain Losses

Looking at the breakdown of losses in apparatus porcelain manufacture (page 179) we find defects that can directly be traced to the poor pugmill operations.

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(1) Westinghouse Patent, 1,615,800, 1/25/27.
(2) Locke Patent, 1,717,996 , 1/18/29.
(3) Technical Reports LK-134-CR (1955), LK-158-CR (1957).

Lamination in blanks made on "soft" pugmills can be caused by not keeping the feed hopper filled, resulting in the loss of vacuum. Never mix hard and soft clay in the pugmill. More on this subject found on page 80 of this Handbook.

If very soft clay is used, the vacuum chamber tends to fill up and must be opened to remove the piled-up mass of clay. Then, starting again, the clay in the bottom auger may not be properly "de-aired", which also may give some laminated blanks.

Worn augers, i.e. too much clearance between barrel and auger diamter, causes slipping and shearing of the clay with a poorly compacted structure, and "flange cracks", found in dry inspection, but also after firing.

In hard pugging operations, "slugs" i.e. hard lumps are occasionally found, left over from last day's pugging. By keeping the shredded clay in the vacuum chamber moist (spray water or wet sponge, etc.) such hardening can be prevented.

Chipping in turning can be avoided by keeping the (carboloy) tools sharpened.

<u>Hot Pressing Suspension, Pintype and Fog Type Insulators (Figures 2 and 3, page 175-176</u>

Compared with losses in this line of work of several years ago, present lossws are low and much of the reduction of losses in this area is due to semi-automatic equipment, operation and control methods. The double-die extrusion on the pugmill for the 10" suspension insulator (1840) and pintype insulator has eliminated practically all head cracks, formerly a substantial cause of losses.

A similar, two blank extrusion die should also be used for the 6" (79004) which should lower the high amount of head cracks in these insulators.

Pinhole cracks are caused by using a cold plunger which results in suction as the plunger is released. Too hot a plunger results in "burns", i.e. a pitted surface. Very little trouble with burns has occurred now on the hot-press line.

The type lubricating oil used on hot plungers is important and the proper oil mixture, as specified in manufacturing instructions must be maintained.

Casting Losses

The casting operation is a very important one and requires particular attention of the details of control and experience.

Cast insulators are large and expensive and the monetary loss is, therefore, higher than in any other type of ware. It is also difficult to reclaim (refire) defective large bushings and, if not fired very carefully and slow, losses due to cooling cracks may be high.

The following are the most important factors that should be controlled:

a. Casting must be of the right composition, viscosity, and must be properly deflocculated. Over deflocculated slip causes dark streaks and cracked ware in such areas (see page 61 of this Manual).

b. The use of wet molds prevent proper removal of moisture from the casting slip with resulting tendency to a variation of difficulties including slump, cracks, and pinholes.

c. Defective molds can cause increased casting losses. The mating surfaces of molds should fit properly otherwise these surfaces can result in leakage and defective parts.

d. Molds must be smoothly and uniformly filled. Fast filling may entrap air and result in losses. Dry molds which have not been used for some time should be sprayed with water to moisten the casting surface.

e. Adequate headers must be provised and should be kept full (see page 64 of this Manual).

f. It is very important that cores be pulled at the proper time. Pulling cores too late can result in cracked parts.

g. After casting parts are quite thixotropic and should be protected from vibration otherwise slump may result.

h. In dry finishing cast parts which are to subsequently glaze jointed, it is most important that the mating surfaces be accurately finished to the required angles so that they will properly match each other, otherwise defective glazed joints may result.

i. Old and sour (fermented) slip should be treated by adding a small amount of formaldehyde; gases in fermented slip cause entrapped air blebs in the unfired and fired insulators.

j. Pinholes are often introduced by filling the mold too fast, the rotary filling device developed (and patented) for this purpose by the writer has eliminated such defects.

Many of these various factors listed here as contributing to manufacturing losses are contained in the Standard Operating Instructions and it most important that these are constantly followed and observed.

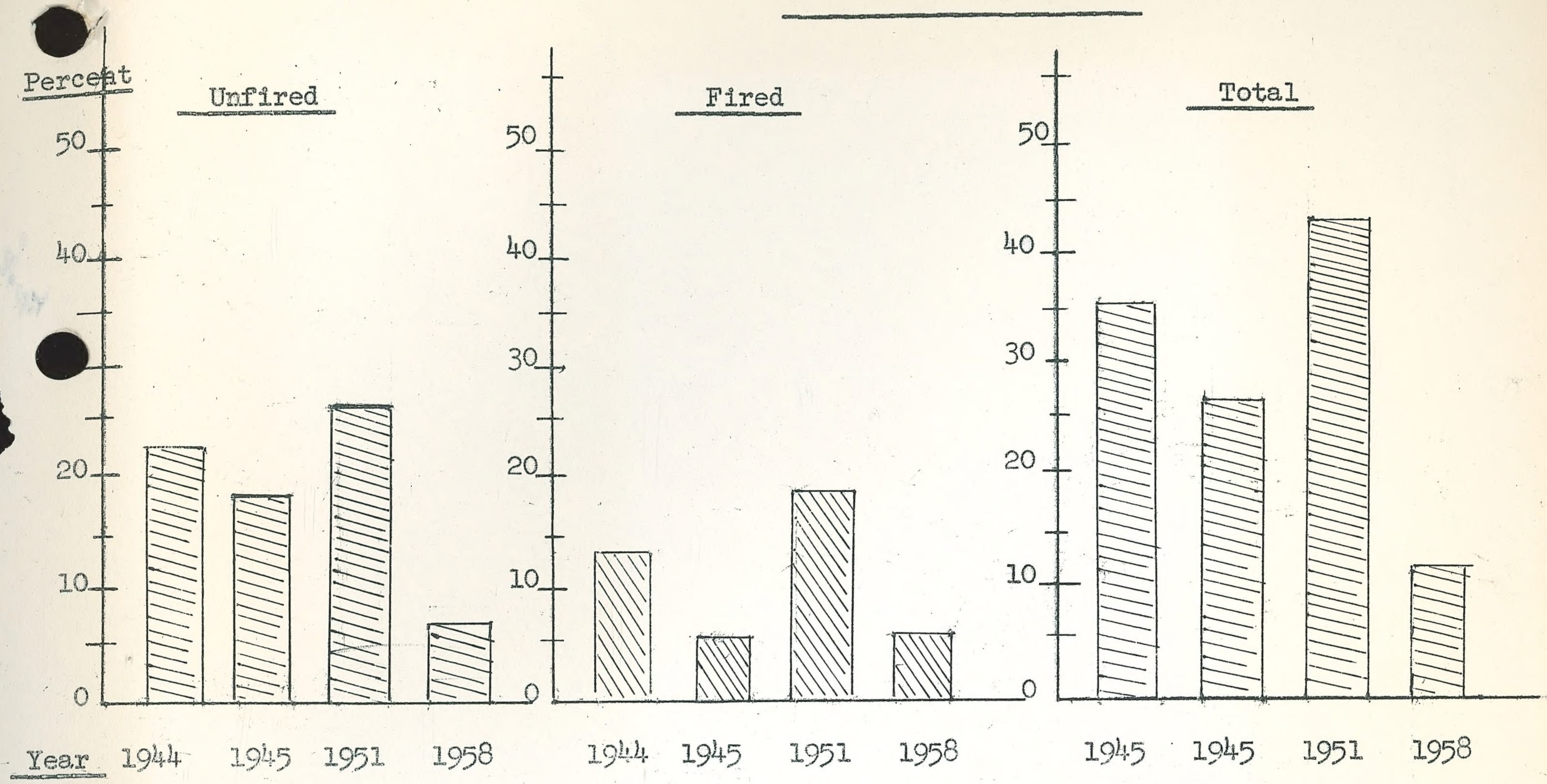
The question now arises, what progress has been made in loss reduction over the past years and how losses compare with those of former years?

To answer this question two loss data charts have been prepared which are shown on page 187. In the area of the now mechanized suspension insulator line we have had, in recent years, rather successful operations. Here, the losses are very low compared with, for instance, those of 1951. The reason for high 1951 losses in this field were due to the unwise adoption of "dry-mixing" instead of the conventional wet-mixing and filterpressing methods of body preparation. An unfavorable plastic body composition (abandoned early in 1952) and poorly controlled, oil-fired kilns, all added to these high manufacturing losses.

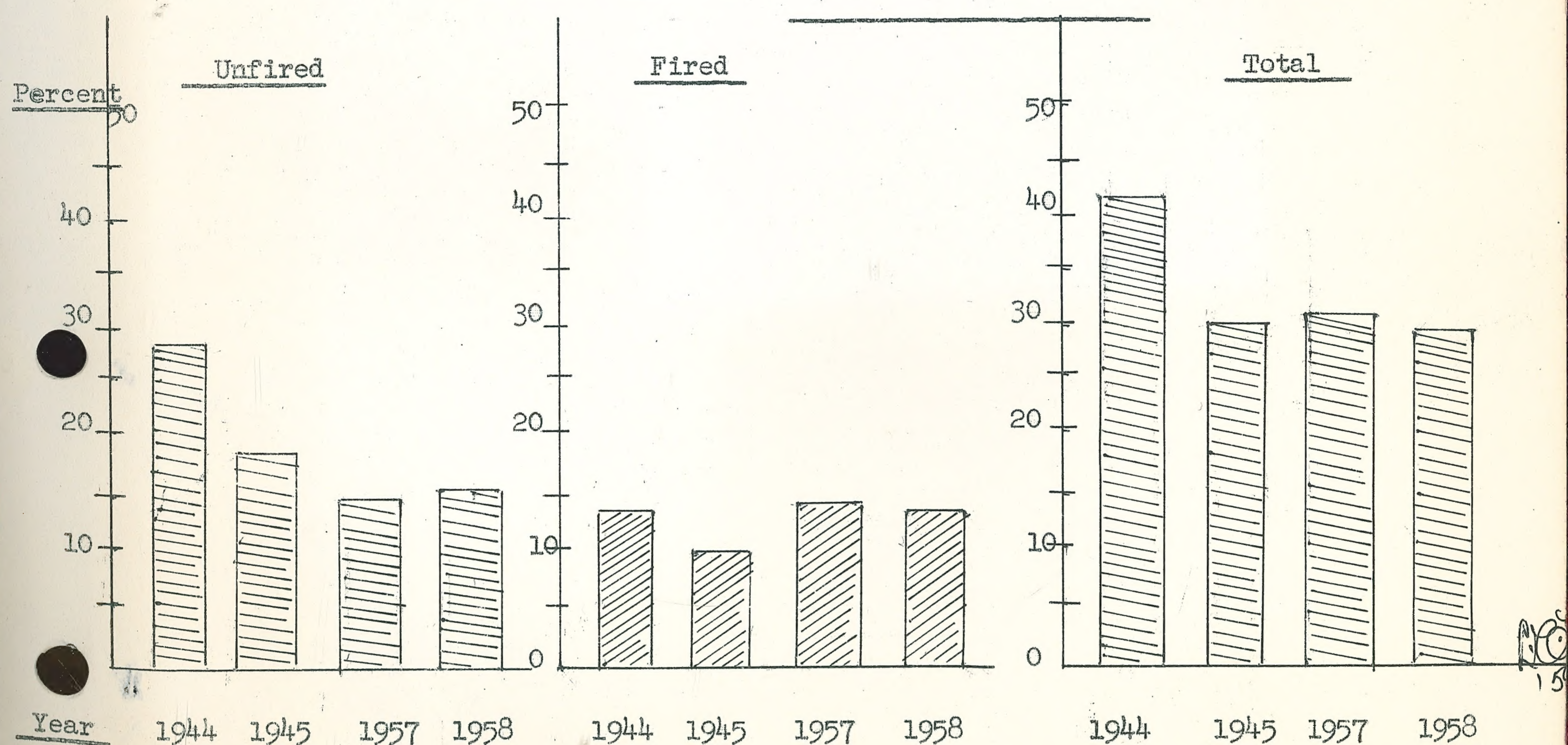
We have not been as successful in items made by pug and turn and jigger methods and there is great room for improvements. Better designed machinery, especially pugmills, more careful systemized methods and procedures, etc., should in this line of work, also bring better results.

The writer concludes that, from his personal experience of more than forty years in insulator manufacture, a systematic and continuous program by fault analysis, by exhibits of defective ware and by prompt corrective action, manufacturing losses can be kept under control and reduced with subsequent lowering manufacturing costs.

Manufacturing Losses - Suspension Insulators



Manufacturing Losses - Apparatus Porcelains (Pug-and Turn)



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